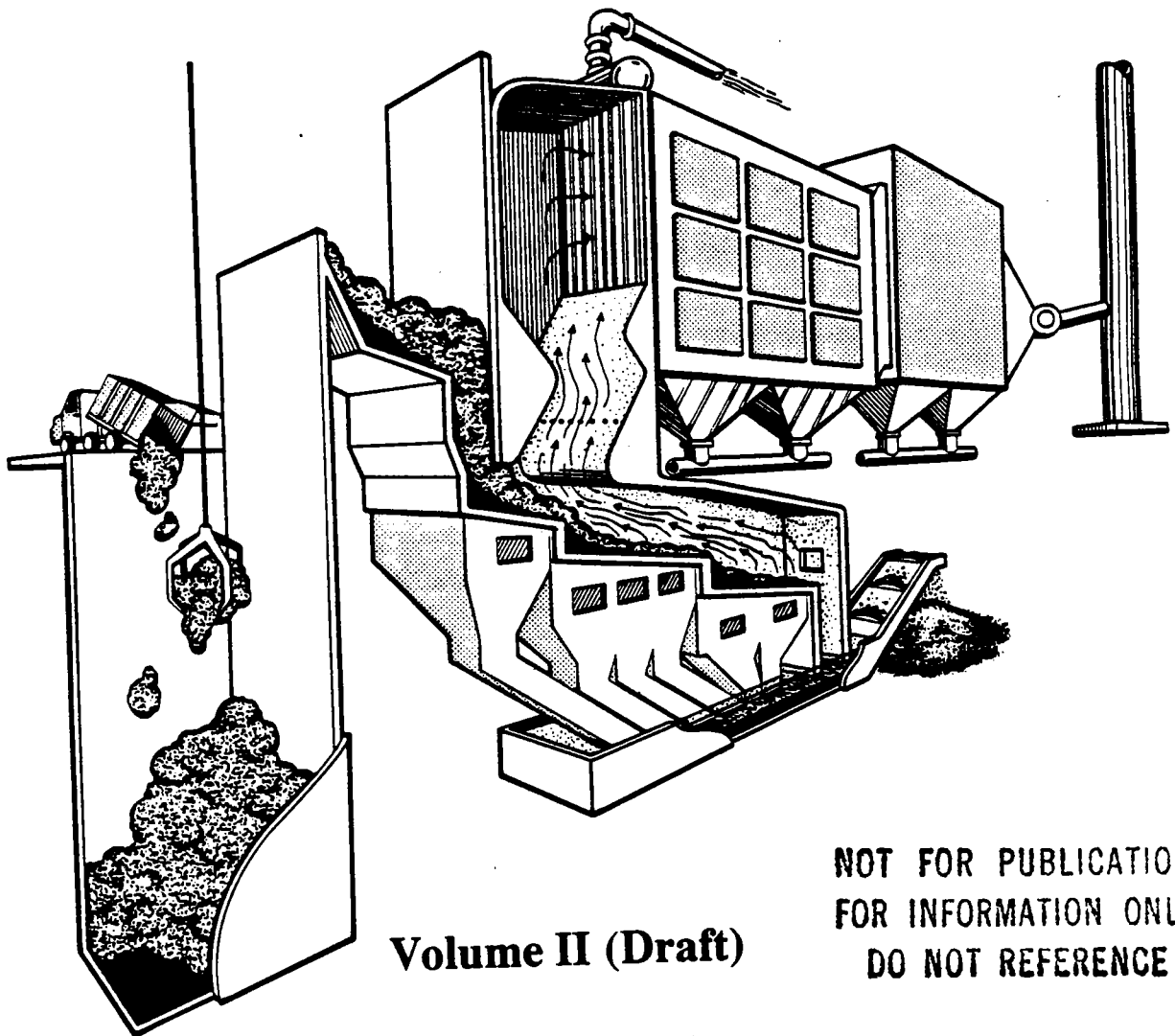A-89-08
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National Incinerator Testing and Evaluation Program

The Combustion Characterization

of

Mass Burning Incinerator Technology

Quebec City

Volume II (Draft)

Main Report

September 1987

Lavalin

NATIONAL INCINERATOR TESTING AND EVALUATION PROGRAM

MASS BURNING INCINERATOR TECHNOLOGY
QUEBEC CITY

VOLUME II

MAIN REPORT

COMPILED BY

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for

Environmental Protection Service
Environment Canada

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1.0 INTRODUCTION

Major concerns are raised repeatedly with both existing and proposed Municipal Solid Waste (MSW) incinerators related to emissions and their environmental impact. Historically, poorly designed, controlled and/or operated incinerators have resulted in environmental detriment and nuisances. More recently, sampling and analytical techniques have improved so significantly that the release of potentially toxic metals and organics from these incinerators has become an issue.

Environment Canada has recognized these issues and concerns and has developed the National Incinerator Testing and Evaluation Program (NITEP). Clearly, such test programs are required to establish a scientific data base to permit experts to determine how incinerator design, combustion characteristics, methods of operation and control systems affect the flue gas content of classical and potentially toxic pollutants.

The multi-faceted and comprehensive National Incinerator Testing and Evaluation Program (NITEP), designed to address environmental and health concerns from municipal refuse incinerators, is now well underway. In Phase I of NITEP, criteria for the selection of municipal solid waste incinerators suitable for testing and evaluating were established. Based on the established criteria, three candidate incinerators were selected. The generic incinerator designs chosen were:

- a two-stage combustion (modular technology) system;
- a waterwall moving grate mass burning system; and
- a Refuse Derived Fuel (RDF) suspension burning system.

These designs encompassed projected future trends in incineration technology. The first candidate selected was the two-stage combustion facility in Parkdale, Prince Edward Island, a suburb of Charlottetown. The plant is owned by the PEI Energy Corporation and operated by Tricil Limited. The second candidate selected was the moving grate mass burning facility in Quebec City, owned by "Communauté Urbaine de Québec" (CUQ) and operated by Montenay Inc., and is the subject of this report. The third facility has yet to be selected.

Phase II involved establishing programs to develop field test protocols, evaluate each incinerator and undertake design modifications as required to bring the unit under test, up to modern standards. The PEI field testing program was conducted during November and December of 1984 and is reported in "The National Incinerator Testing and Evaluation Program: Two-stage Combustion (Prince Edward Island" Report EPS 3/UP/1, September 1985.

The Combustion Assessment Program for the Quebec Incinerator consisted of an extensive field effort to collect process and emission data over a range of different operating conditions. In this respect, it was very similar to the effort undertaken at the PEI EFW facility. However, since the Quebec facility was designed more than a decade ago, its design was not considered comparable to modern mass burning system designs and, accordingly, a design modernization aspect was added to the original

program. The Design Modernization Program (Section 2.4) identified the design modifications that were required on the Quebec system in order to upgrade the facility to current state-of-the-art.

This report presents the second part of Phase II of NITEP, namely the Combustion Assessment Program for the mass burning Quebec Incinerator, and an extensive description of the process modifications that were made prior to actual testing.

1.1   REPORT OUTLINE

This volume (II) is the main report and presents the results of the Quebec City field testing program conducted in May through July of 1986. The report documents the following:

- a description of the process and equipment details relevant to the test program and NITEP objectives including modernization to upgrade the facility to state-of-the-art (Chapter 2);

- a description of the rationale and approach of the test program and tested component (Chapter 3);

- a description of site modifications to accommodate the testing phase (Chapter 4);

- complete descriptions of all instrumentation, sampling and laboratory methods employed in the test program (Chapters 5 and 6);

- a description of the quality control procedures and level of responsibility of the different contractors (Chapter 7);

- an inventory of background historical emissions (Chapter 8);

- a description of the Characterization Tests, including a discussion of all relevant operating variables for each test run compared to normal operation and to design ratings; results; impacts of process changes; and the rationale behind selecting the Performance Test Matrix (Chapter 9);

- a description of the sampling conducted under the Performance Test Program, including detailed results of all monitored conditions; a detailed matrix of all analyses; and any comments and observations deemed relevant (Chapter 10);

- the meaningful process and emission correlations resulting from single linear regression analysis and multi-regression analysis (Chapter 11); and

- the resultant conclusions drawn from this testing program related to combustion and operation and the overall program; recommendations for future sampling programs and further work with the NITEP Quebec data (Chapter 12).

1.2   OWNER AND OPERATOR CONTRACTS

The Quebec Incinerator Plant is owned by the Quebec Urban Community (QUC) and is located in the northeast end of the city, in a mixed residential, commercial and industrial area near the Reed Paper Ltée pulp and paper mill. It receives municipal, commercial, and suitable industrial solid waste collected by the Quebec Urban Community, as well as from several other municipalities and private contractors. A tipping fee of $50.57 (Canadian) per tonne of refuse was charged in 1986. Ash from the plant is transported to a designated landfill site by private contractor. Montenay Inc. operates the plant under a comprehensive operations contract that includes the responsibility for all maintenance and servicing.

The primary operating criteria of the plant are to:

● incinerate the suitable refuse received (i.e. excluding hazardous and non-combustible loads), and
● maximize steam output.

All of the available steam generated by the plant is sold to Reed Paper Ltée. The steam supply contract calls for steam to be delivered at a relatively steady flow (7%) and specified pressure range. Reed Paper Ltée pays $13.87 (1986 Canadian dollars) per tonne ($6.29 per 1000 lbs) of steam delivered. Steam condensate returns to the plant at a rate of approximately 50% of steam supplied. The EFW plant makes up the balance of the feed water requirements from the municipal water system.

The incinerator is in operation 24 hours per day and 363 days per year with two complete (24-hour) shutdowns per year for major inspection of the Reed steam plant and steam line supply to Reed.

Usually the Quebec Incinerator produces steam from two or three and rarely four units, depending on the refuse availability.

The monetary aspect of the contract between Reed Paper Ltée and the "Communauté Urbaine de Québec" is renegotiated each year based on the cost for Reed Paper to produce the steam with their installation.

1.3   NITEP CONTRACT

In view of the importance of the NITEP program and the benefit to the owner/operator to have a good understanding of the combustion process under diverse modes of operation, it was agreed between NITEP and the owner/operator that Unit #4 would be available for testing with almost no limitation on the operation. The plant operators fully co-operated with the testing crew, with the installation of the sampling equipment and the operation of the unit. Lavalin was hired by NITEP to be the prime contractor and be responsible for the overall sampling program.

1.4   ASSESSMENT AND REPORTS

To document the considerable quantity of data generated during the test program, the findings were divided into six volumes. Each volume has been compiled with specific reviewers and interest groups in mind. The following lists the information provided in each volume.

1.4.1   Summary Report (Volume I)

The summary report describes the essence of the project and the principal and significant results. It is limited to highlighting significant findings and contains relevant graphs, tables and figures. In addition, it contains brief descriptions of each major program component such as sampling and analytical methodologies, objectives, and conclusions.

1.4.2   Main Report (Volume II)

The main report contains a complete description of all relevant program details with brief outlines of the methods employed as well as presentation of the results obtained. In addition, a discussion of the approach and key findings of the Characterization and Performance Test studies are provided.

1.4.3   Methodologies (Volume III)

This report provides details on all methodologies employed during the test program, emphasizing any variations from the established protocols. The rationale is provided for any variations employed. Appendices are provided which contain copies of all standard protocols used.

1.4.4   Detailed Data Report (Volume IV)

The detailed data report contains printouts of summary field data and of analytical results as appropriate back-up for all tables and graphs presented in the texts of all other volumes.

1.4.5   QA/QC Report (Volume V)

An independent Quality Assurance/Quality Control (QA/QC) Report was prepared under the auspices of the Ontario Ministry of the Environment (MOE) through their contractor, Concord Scientific Corporation. This report provides an unbiased assessment of the sampling and analytical methodologies employed during and after the field test program.

1.4.6   Leachate Assessment (Volume VI)

Ash and refuse collected for the five Performance Test modes of operation were subjected to a series of tests to evaluate the leachability of both organic and inorganic contaminants. This report presents the findings of the leachability tests on both a short- and long-term basis. The Wastewater Technology Centre of Environment Canada carried out the leachate tests.

2.0   PROCESS AND EQUIPMENT DESCRIPTION

2.1   GENERAL

The Quebec City Municipal Solid Waste (MSW) Incinerator Plant utilizes moving grate, waterwall incineration technology to mass burn as-received refuse. The plant produces super-heated steam using flue gas heat recovery boilers.

The plant was originally designed and built under the direction of S.N.C., with Dominion Bridge providing the major equipment. The incinerator units were designed by Von Roll for Dominion Bridge.

Two of the units were started in 1974, and all four have been in operation since 1975. In 1979 an arch was installed above the drying and burning grates of each incinerator. The modifications were designed for the CUQ by Shawinigan Engineering, assisted by Dominion Bridge and consisted primarily of the addition of a lined waterwall arch over the burning grate. Sidewall overfire air ports were abandoned in favour of frontwall ports beneath the arch. In 1985/86 the consortium of Lavalin/Roche modernized Unit #4 prior to the NITEP field test, as described in Section 2.4.5.

The principal plant elements, as shown in Figures 2.1 and 2.2, and as described hereafter, include:

- a weigh scale system for incoming trucks;
- a fully enclosed, single-side entry, refuse tipping storage pit and crane system;
- four incinerators burning as-received refuse, each nominally rated at 227 tonnes per day;
- an ash quench tank, drag chain, storage pit and crane system; and
- a single flue stack (approximately 55 m in height) common to all 4 incinerators.

Each incinerator consists of:

- a vibrating feeder-hopper,
- a water-cooled feed chute,
- drying/burning/finishing reciprocating grates,
- a refractory-lined lower burning zone,
- a waterwalled partially-lined radiation chamber,
- a vertical tube mechanically-rapped waste heat recovery boiler with superheater and economizer tube sections,
- a two-stage electrostatic precipitator,
- an induced draft fan, and
- an ash quench tank with a drag chain ash removal system.
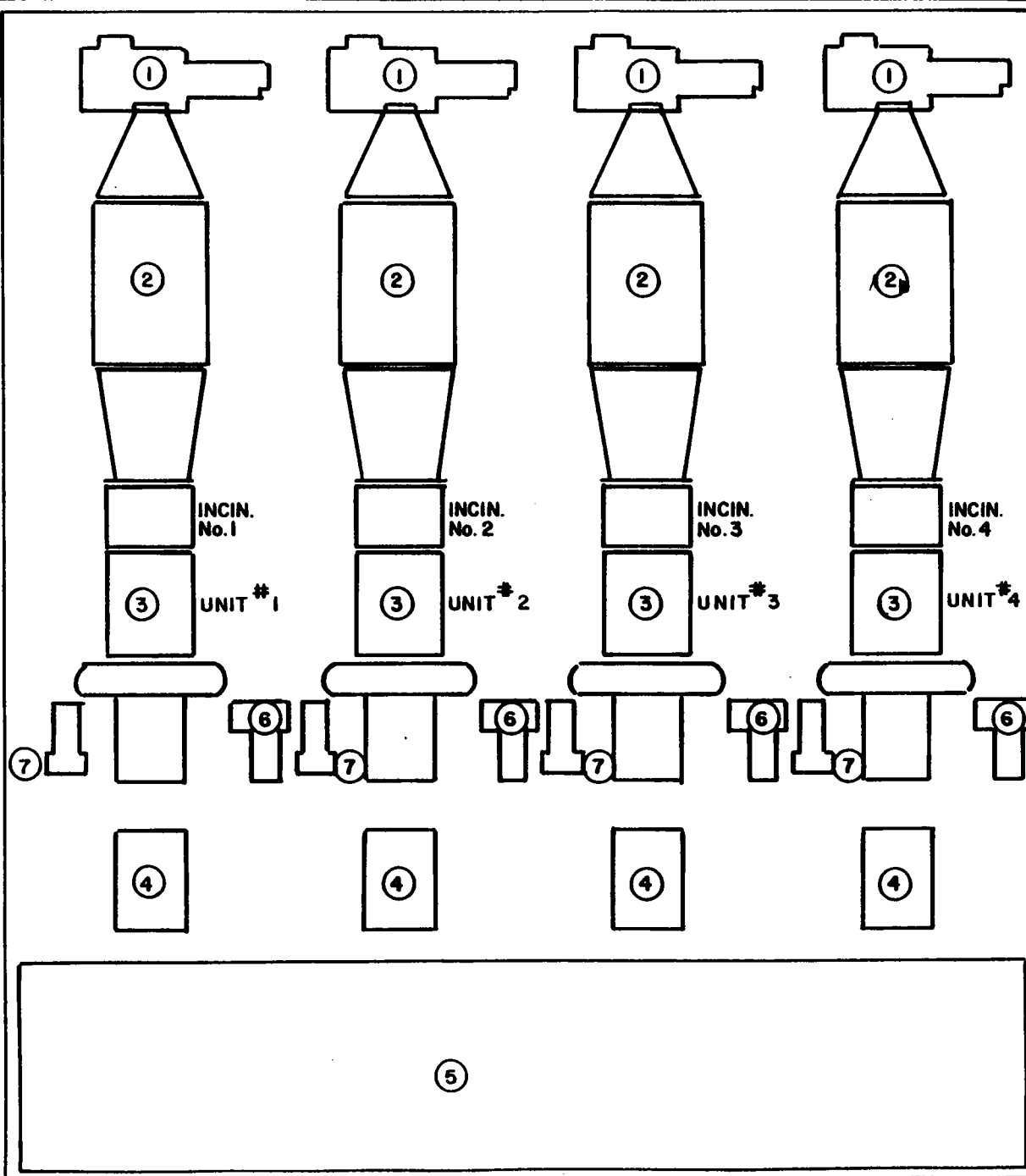
1. INDUCED DRAFT FAN
2. ELECTROSTATIC PRECIPITATOR
3. INCINERATOR /BOILER
4. VIBRATING FEEDER/HOPPER
5. REFUSE STORAGE PIT
6. PRIMARY AIR SUPPLY FAN
7. SECONDARY AIR SUPPLY FAN

1. VENTILATEUR DE TIRAGE
2. ELECTROFILTRE
3. INCINERATEUR & CHAUDIERE
4. DISTRIB. VIBRANT & TREMIE
5. FOSSE A DECHETS
6. VENTILATEUR AIR PRIMAIRE
7. VENTILATEUR AIR SECONDAIRE

INCIN. No.1   UNIT #1
INCIN. No. 2   UNIT #2
INCIN. No. 3   UNIT #3
INCIN. No. 4   UNIT #4

Figure 2.1

• USINE D'INCINERATION DE QUEBEC
SCHEMA D'AGENCEMENT

• QUEBEC INCINERATOR
PLANT LAYOUT

- Fumées
- Flue Gases

- Electrofiltre 2 Champs
- Two Stage Electrostatic Precipitator

- Stack
- Cheminee

- Crane
- Pont Roulant

- Chambre de Rayonnement
- Radiation Chamber

- Cabine du Grutier
- Crane Operator Booth
- Trémie & Distribution d'Alimentation
- Vibrating Feeder Hopper

- Vertical Tube Boiler Section
- Chambre de Convexion

- Induced Draft Fan
- Ventilateur Tirage Induit

- Drop Chute
- Goulotte d'Aliment

- Manutention des Cendres
- Ash Handling Crane

- Siftings Hopper
- Trémies Sous Grille

- Camion à Cendres
- Ash Truck

- Refuse Storage Pit Fosse de Stockage des Dechets

- Niveau d'eau
- Quench Water Level

- Fosse à Cendres
- Ash Storage Pit

- Ash Quench Tank and Drag Chain
- Cuve d'Extinction et Chaine Trainante

Figure 2.2
QUEBEC INCINERATOR
Schematic Cross – Section

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2.2 PLANT SITE

The site layout is shown in Figure 2.3. The plant is on a 17,550 m² lot. The incinerator building is a painted steel frame building covering approximately 4460 m² of the site. Paved areas provide access and parking for refuse vehicles, ash haulage, service and operating personnel. Because of the limited site area and the elevated tipping floor arrangements, there is one ramp to access the tipping floor area and a separate ramp to the maintenance area.

2.3 REFUSE HANDLING SYSTEM

Trucks enter the site, pass over an attended truck scale, enter the plant via an elevated access ramp and dump their load of refuse into the refuse storage pit. The trucks exit by the same access ramp and truck weigh scale station. Refuse pit capacity is 10,000 m³ or approximately 2100 tonnes of refuse (assuming 208 kg/m³). Any material that is considered to be inappropriate for the incineration process such as a large appliance, is removed from the pit by the crane, and transferred to a designated landfill site or scrap metal facility. The two overhead cranes, each with 3 m³ buckets are used to clear the tipping face of the pit, to pre-mix and to charge refuse into each vibrating feeder/hopper system. The refuse is then fed by the vibrating feeder on an as-required basis onto the incinerator drying grate via the water-cooled feed chute.

2.4 INCINERATOR UNITS DESCRIPTION

2.4.1 General

The refuse incineration units are equipped with reciprocating grates and furnaces which were originally designed by Von Roll, and integrated with boilers designed by Dominion Bridge. Each incinerator unit is capable of independent operation and was originally rated at 227 tonnes per day when burning 13,950 kJ/kg (6000 BTU/lb) refuse. The units are designed for mass burning as-received refuse and operate under slightly negative (pressure) conditions.

Refuse is fed to the incinerator by a vibratory feeder/surge hopper, which is directly supplied with raw refuse by the storage pit crane. The vibratory feeder supplies refuse to a vertical water-cooled feed chute which in turn directs the waste onto the first grate of the furnace. The vibratory feeder automatically maintains a column of refuse or "plug" in the feed chute to prevent undesirable air entering the combustion area.

RECEIVING RAMP

SERVICING RAMP

UNIT 4 / INCIN. No. 4

UNIT 3 / INCIN. No. 3

UNIT 2 / INCIN. No. 2

SCALE

UNIT 1 / INCIN. No. 1
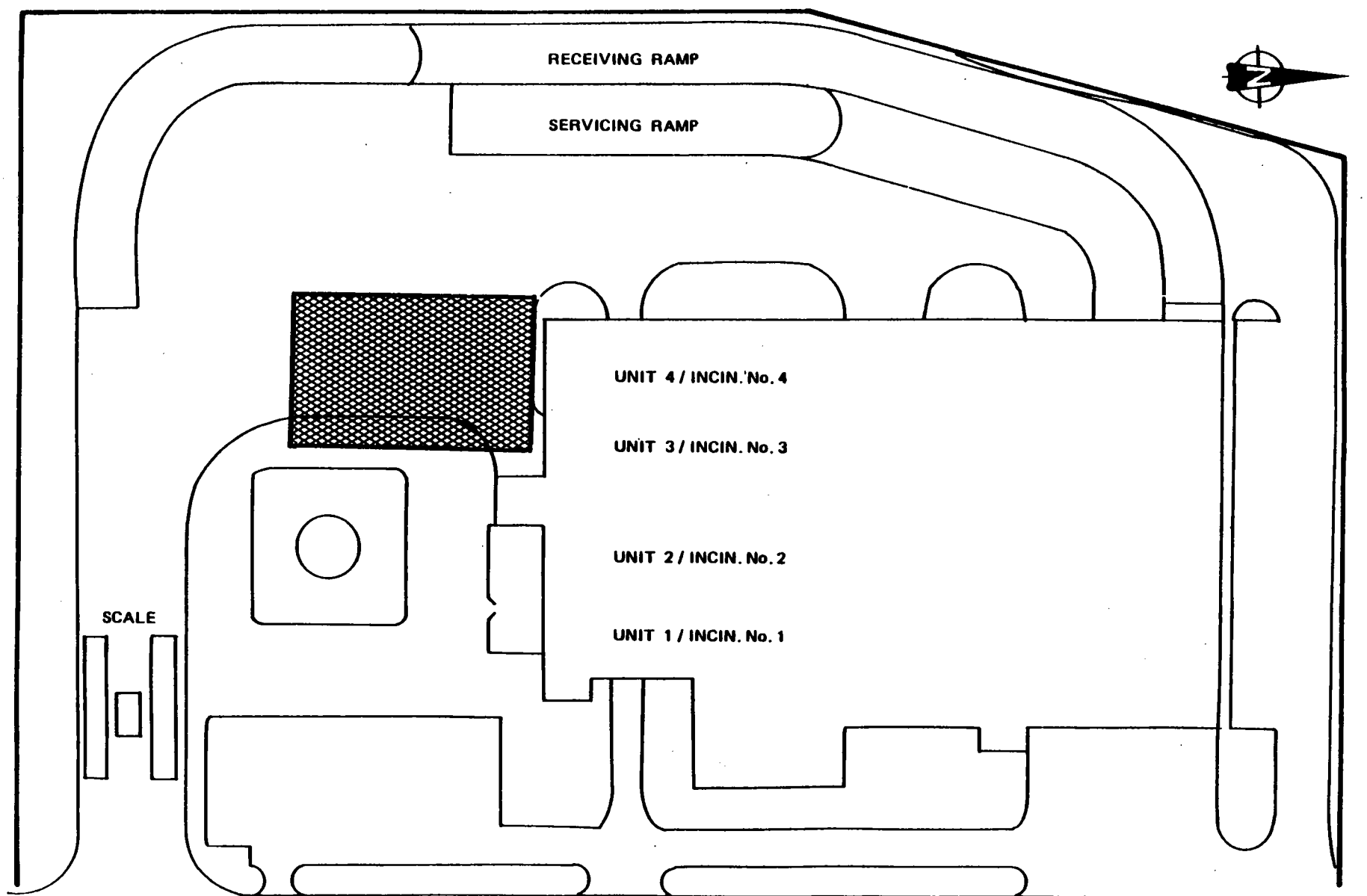
RUE INDUSTRIELLE

Figure 2.3
QUEBEC INCINERATOR

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Three sets of moving grates form the furnace floor. The burning wastes are moved down the length of the furnace by the reciprocating motion of the grate. The first grate (drying grate) meters the flow of refuse from the feed chute onto the main combustion grate (the burning grate) and in turn the burning grate discharges partially burned waste onto the third grate (finishing grate) for final "burn-out" of the waste, discharging ash off the end into the quench tank below. Each grate can be operated independently by speed-adjustable hydraulic rams. The movement of the alternating stationary and oscillating longitudinal grate block rows, cause the waste to move in small increments down the grate. Under normal operating conditions each of the 3 grate speeds is adjusted to obtain the desired throughput and the best waste burden profile on each grate. To assist the waste travel, the grates are placed on a 15° slope with vertical drops between the grate sets.

The main stream of bottom ash discharges off the end of the finishing grate and falls into the quench tank below via an ash drop chute. Hoppers below the grates collect and direct fine material or "siftings" which drop between the grate blocks to the quench tank below. The siftings hoppers also act as a plenum, providing a means of admitting primary combustion air through the grates and into the furnace. Each hopper is pressurized by the primary combustion air fan. Air leaves the hoppers and passes up between the grate block rows, thereby supplying a relatively even distribution of air to the refuse bed and the combustion zone above. This air also provides cooling to limit the temperature of the grates. To prevent combustion air escaping from the siftings hoppers, each chute bottom outlet is submerged below the quench tank water level thereby forming a seal. Similarly the ash drop chute is submerged to prevent undesirable air entering the unit.

The lower furnace wall (the burning zone) is lined with alumina refractory. The roof of the furnace and the radiation chamber are constructed with side-by-side welded tubes through which boiler water is circulated for cooling purposes and heat recovery. This construction is referred to as the waterwall. The lower portion of waterwall is coated with heat-resistent refractory lining to protect the tubes from direct exposure to flames. The roof and upper sections of the waterwall in the radiation chamber near the boiler inlet are exposed to the flue gas to improve heat recovery.

Flue gases leaving the radiation chamber or vertical flue section of the combustion chamber enter the heat recovery boiler via vertical screen tubes. The boiler is a vertical multitube boiler with convection, superheater and economizer sections which are cleaned by a mechanical rapping system. Revolving hammers attached to a horizontal driving shaft, operate on a timed sequence, periodically rapping the soot from the tubes. The rapped tubes release particulates into the hoppers below. Heat is removed from the horizontal flue gas flow by vertically hung tube banks. The boiler outlet temperature drops to between 200°C and 260°C, depending on the operating condition of the boiler.

Cooled flue gases leaving the boiler section enter a two-stage electrostatic precipitator for particulate removal, ultimately exiting to the atmosphere via the induced draft fan system and the exhaust stack.

2.4.2   Pre-NITEP Furnace Design

Based on studies undertaken by Shawinigan Engineering Ltd. in 1978, a water-cooled refractory-lined arch was installed over the drying grate and burning grate, as shown in Figure 2.4. The refractory arch was installed in the furnace roof to reduce the particulate lift-off and improve the combustion efficiency and ash burnout achieved by the refuse burning units. The original overfire air ports (along the side walls above the burning grates) were abandoned in favour of 20 new overfire air ports located in the front bull-nose, supplying air to the underside of the inclined section of the arch.

In the original design, auxiliary fuel burners were installed in a separated combustion section of the upper front of the radiation chamber. This ancillary fuel burning chamber occupied approximately 25% of the upper chamber. These burners were never utilized.

Primary airflow was drawn from the refuse pit area. Primary air was supplied and distributed to the 5 siftings hoppers or zones located beneath the grates as shown in Figure 2.5. The supply air duct to each hopper was fitted with individual, manually set, motorized dampers (the drying grate damper was manual). Air was distributed to the grates by the operator manually setting the balancing dampers associated with each section, based on the static pressure and percent damper opening of each hopper. Generally, each set-point was not changed and actual air distribution varied with refuse bed depth. No flow rate indication was provided.

The primary airflow total was modulated continually by a guide-vane damper located at the inlet of the 68,000 m^3/h supply fan. The total primary air was automatically paced by steam flow (i.e. airflow was increased on lower-than-set-point steam production and decreased on higher-than-set-point steam production).

The secondary air was introduced at a manually set fixed rate through the 20 nozzles located in the front bull-nose beneath the water-cooled arch. The secondary air fan was rated at 23,800 m^3/hr with a static pressure of 50 cm of water, and drew air from the refuse pit area through a motorized damper. Automatic adjustment of the secondary airflow in response to the upper burning zone temperature (i.e. flow increased as temperature increased) was originally provided, however, this system was not utilized. Typically secondary air was kept to a minimum (i.e. 10% of the total combustion air supply).

2.4.3   Pre-NITEP Furnace Control System

The control panel was divided into five parts. The centre section display included instrumentation and controls for the common services, such as total plant steam and pressure, total send-out steam, and water supply.

The other four sections displayed the following:

- the status of the operation and control for each incinerator unit, including alarms;

- STEAM DRUM.
- BALLON DE VAPEUR.

- PAROI DE TUBES A EAU
- WATERWALL MEMBRANE.

- SCREEN TUBES.
- TUBES ÉCRAN

- VERTICAL FLUE CHAMBER.
- CHAMBRE DE RAYONNEMENT

- DIÈDRE AVANT ORIGINAL
- EXISTING FRONT BULL-NOSE.
- ALIMENTATION DÉCHETS
- REFUSE FEED.

N

OVERFIRE AIR

- AFFICHE A REFROIDISSEMENT PAR EAU
- EXISTING WATERWALL ARCH.

- GRILLE DE SÉCHAGE
- DRYING GRATE.

- CHICANE EN REFRACTAIRE
- EXISTING REFRACTORY CHICANE.

- GRILLE DE COMBUSTION
- BURNING GRATE.

- ÉCOULEMENT DES GAZ
- FLUE GAS FLOW.

- GRILLE DE FINITION
- FINISHING GRATE.

- PLANCHER DE SERVICE
- OPER. FLR.

1 ST CONV SECT. | 2 ND CONV SECT. | SUP. HTR.

1ER FAISCEAU DE CONVEXION | 2EME FAISCEAU DE CONVEXION | SURCHAUFFEUR

- TRÉMIE A SUIE
- BOILER DUST HOPPER

FIGURE 2.4

- QUEBEC TEST INCINERATOR
  227 MT/D
  1978 DESIGN
- INCINERATEUR DE QUEBEC
  227 t/j

PAROI DE TUBES
A EAU
WATERWALL
MEMBRANE

GAS
GAZ

SCREEN TUBES

1st CONV. SECT.
1ÈS FAISCEAU DE CONVEXION

2nd CONV. SECT.
2ÈME FAISCEAU DE CONVEXION

SUP. HTR.
SURCHAUFFEUR

RADIATION CHAMBER
CHAMBRE DE RAYONNEMENT

DIEDRE AVANT
ORIGINAL
EXISTING FRONT
BULL-NOSE

UPPER REAR
BULL-NOSE

ALIMENTATION
DECHETS
REFUSE
FEED

GAS
GAZ

OVERFIRE
AIR

SECONDARY
AIR

TREMIE
A SUIE
BOILER
DUST
HOPPER

GRILLE DE
SECHAGE
DRYING
GRATE

LOWER
BULL-NOSE

GRILLE DE
COMBUSTION
BURNING
GRATE

ECOULEMENT
DES GAZ
FLUE GAS
FLOW

PRIMARY
AIR SYSTEM

GRILLE DE
FINITION
FINISHING
GRATE

FIGURE 2.5

QUEBEC
INCINERATOR
1986 DESIGN (MODIFIED)
INCINERATEUR DE
QUEBEC

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- controllers/indicators for air supply and grate speeds, static pressures and temperatures at various points in the system; and

- recorders for steam rate, combustion air and opacity.

All controllers were of the pneumatic type and process recorders were monitored by chart recorders.

2.4.4   Design Modernization Program

Planning

In January 1985, Lavalin Inc. was retained to undertake a planning study related to the then-proposed NITEP test program at the Quebec MSW incinerator. An extensive field testing effort was made to collect process and emission data over a range of operating parameters. Following this, the extent of the design modifications that would have to be undertaken in order to approach the present state-of-the-art of such systems was identified in light of the requirements of NITEP.

Furnace Modelling

In the summer of 1985 MacLaren Plansearch Inc., a division of Lavalin, was retained by "La Coentreprise PIETTE/ROCHE" and the "Communauté Urbaine de Québec" (CUQ) to conduct furnace gas-flow pattern analysis. The purpose of this analysis was to examine the existing furnace flow patterns and optimize the furnace configuration and overfire air flow patterns so that the need and/or the appropriateness of the modernization could be verified.

The actual modelling was conducted by NELS Inc. in St. Catharines, Ontario.

The main objectives of the examination were to achieve the following:

a)   improve the turbulence at the secondary air zone to provide thorough mixing of combustion air and combustible gases;

b)   examine the effect of the increased retention time in the furnace as a result of removing the existing auxiliary burner chamber and thus increasing the effective furnace chamber volume;

c)   examine the effects of chamber configuration and secondary (overfire) air on flow distribution into the boiler inlet;

d)   optimize the location of the secondary air nozzles and improve nozzle design to achieve a);

e)   optimize the shape and location of the "bull-nose" (see Figure 2.5) to achieve b) and c); and

f)   investigate the impact of varying front and rear secondary air ratios on a), b) and c).

Flow Model

The project consisted of the construction of a 1/6-scale airflow model of a 227 tpd Von Roll incinerator. The Plexiglas and wood model was designed to enable the insertion or deletion of various wall or roof panels to allow testing of various furnace design configurations.

Flow model tests were first done on a model configuration that depicted the 1978 design. In addition, a number of configurations and different secondary nozzle configurations within the furnace were selected for evaluation using a range of primary/secondary air ratios. Furnace flow patterns for the various configurations were traced by depositing sawdust and cork dust on the grate before startup, and by injecting smoke under the grate and through individual secondary air nozzles.

To document the various events and allow an assessment of the design, flow measurements were taken at each duct and the flow patterns were videotaped. The configuration which provided optimum mixing and even airflow pattern in the upper chamber was selected as the basis for the furnace reconstruction.

Discussion

The 1978 design, depicted in Figure 2.4, resulted in very high gas velocity at the rear wall of the furnace radiation chamber due to the narrow opening between the upper and lower part of the furnace at the end of the arch. The remaining areas of the furnace radiation chamber exhibited low gas velocities and even experienced some downward flow near the auxiliary burner cage wall. Significant stratification occurred at the boiler inlet with gas velocity ratios of 3:1 and higher, measured between the lower and upper boiler inlet.

In the modified furnace configuration (Figure 2.5), the lower bull-nose was provided to adopt a furnace configuration which approximated more recent Von Roll designs. This lower bull-nose was intended to maximize the radiation reflection onto the burning and finishing grates to improve ash quality. Another purpose was to "pinch off" the combustion gases in the furnace leaving the finishing grate zone to complete the burning of the volatile gas. Several variations of the lower bull-nose configuration were tested. All seemed to result in minimal changes to the furnace flow patterns.

The addition of an upper new bull-nose (Figure 2.5) in the furnace resulted in the following improvements:

● it reduced the gas vortices in the upper chamber;
● it improved the gas distribution in the upper radiation chamber; and
● it reduced the stratification of the combustion gas at the boiler inlet.

Varying the ratio of front-to-rear secondary air appeared to have a dramatic effect on the combustion gas movement in the upper chamber. (Vortices were created in opposite directions as the ratios reversed, i.e., a front/rear ratio 1 produced a vortex in the opposite direction compared to a front/rear ratio.) The best front-to-rear ratio was 1:1, resulting in the optimal vertical mixing and least stratification at the boiler inlet.

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Summary

A summary of the benefits from the modelling program include:

- the determination of the optimum roof and bull-nose panel configurations;
- the determination of the optimum location of the secondary air nozzles and their size;
- confirmation of the rationale behind the new furnace configuration; and
- useful information was obtained on possible set-points (i.e. critical process parameters) for the startup of the unit.

In total, 51 recorded model test runs were conducted on both the 1978 design and the proposed configurations and flow patterns.

Based on these tests and comparison of the proposed design with the 1978 configuration, the following observations could be made:

- the 1978 configuration effectively used only a fraction of the available upper furnace radiation chamber;

- the 1978 configuration resulted in a high particulate carry-over rate from the burning and finishing grates to the lower level of boiler inlet. This high level was caused by the higher upward velocity resulting with narrow arch opening;

- the high velocity of the gas at the boiler inlet was probably one of the factors causing excessive erosion on the lower part of the boiler inlet screen tubes;

- the retention time in the radiation chamber was limited due to the high velocity flue gases; and

- direct flame impingement probably occurred on the boiler screen tubes.

In summary, it was observed that the proposed modifications produced good mixing and a high turbulent zone above the overfire air nozzles, improved retention time and improved the flue gas distribution at the boiler inlet.

2.4.5   Unit Upgrading

In May 1985, the consortium of Lavalin/Roche was contracted by the CUQ to complete the upgrading of Unit #4 in accordance with the recommendations made by NITEP and as confirmed by flow model study findings.

The upgrading of Unit #4 was completed in March 1986 and included the following modifications. (Refer to Figure 2.5)

a) Radiation Chamber Modification

Essentially, adoption of the bull-nose design and removal of the waterwall arch were undertaken to prevent high upper velocity flue gases, and provide good mixing of overfire or secondary air in the lower portion of the chamber as well as to provide improved gas distribution into the boiler.

The shape of the bull-nose addresses factors such as the directional flow of the flue gas and the limited areas in which overfire air can be introduced. The final bull-nose configurations and overfire air location were determined by Lavalin, supported by the airflow modelling program.

Other radiation chamber modifications included the removal of the auxiliary oil burner cage to increase the radiation chamber volume, thereby increasing flue gas residence time. This work involved removing the internal cage panel, the cage outlet slag tubes and the waterwall roof section over the entire existing flue area. A new roof waterwall panel was then installed at a somewhat decreased angle when compared to the original roof line. This increased the radiation chamber volume by approximately 56 m^3 for a total upper chamber volume increase of about 32%.

b) Primary Air Distribution Modification

Modifications involved providing additional siftings hoppers and air zones beneath the grates, as well as providing dampers and flow monitoring/controlling systems to permit automatic control of the air split to the grates.

With the modified design, primary air is supplied and distributed beneath the grates in 9 separate zones as shown in Figure 2.6. The individual flow controllers maintain a preset percentage of the total flow to be distributed to each hopper. To maintain desired steaming rates, the total primary airflow and distribution splits are modulated continuously.

The original design had only two siftings hoppers below the burning grate: the upstream hopper covered approximately 1/3 of the grate area and was designated as hopper "A", the downstream hopper covered the remaining portion of the burning grate area and was designated hopper "B". To providing hoppers zones of approximately the same size as the latest Von Roll practice, the downstream hopper "B" was split in the transverse direction to provide three, approximately equal, hoppers down the length of the burning grate. The 3 hoppers were divided down the centerline of the incinerator, thereby providing a total of 6 hoppers under the burning grate.

In the old system, the total primary airflow had been continually and automatically paced on steam flow; the proportion of total air to each hopper had been manually set, distribution of the flow to each hopper varying as changes to the refuse bed depth above the grate sections occurred. Based on the plant's historical charts, the total flow-regulating damper continually modulated to provide a fairly even steam flow. However, large swings in airflow (20-60% normally and as high as 0-100%) occurred to maintain the desired steaming rate, resulting in poor air distribution patterns under the grates (i.e. fissures in zones that had shallow beds of refuse and therefore excessive air rates). Also, with these large rate swings and as the total flow decreased, more air would be received by the finishing grate area since the settings of the manually set distribution dampers were rarely changed and the pressure

Primary Air Distribution and Zones

Drying Grate ← → | **Burning Grate** ← → | **Finishing Grate** ← →

17%   12%   9%

2B   3B   4B

1   5   6

Typical Primary Air Hopper

2A   3A   4A

9%   Typical Flow Control Damper   17%   12%   9%   10%   5%

Primary Air Fan
Rating Point; 40,000 CFM at 10" WC
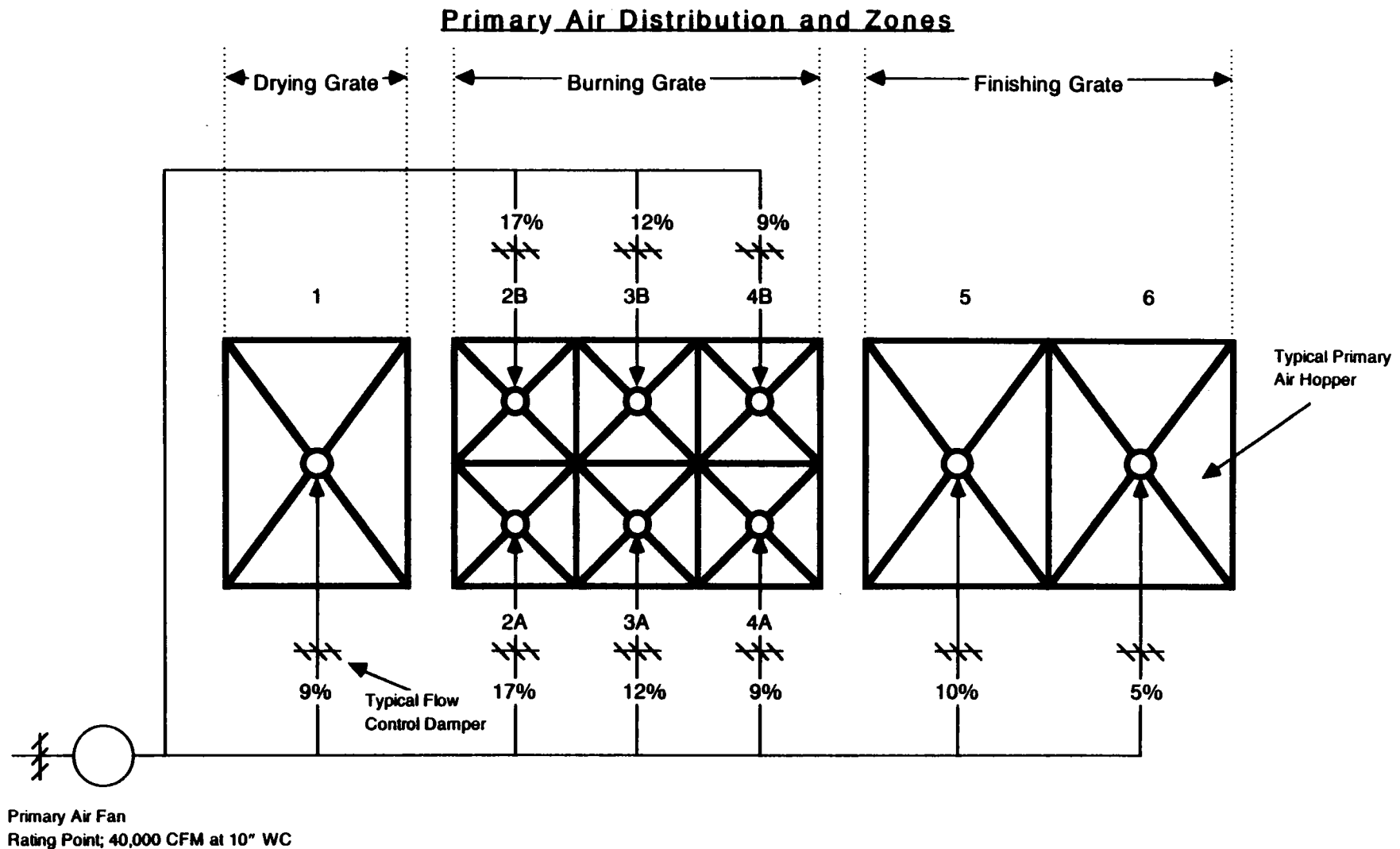
Figure 2.6

QUEBEC INCINERATOR

Combustion Modifications Model Testing

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drop through the bed would be less. Unless the individual branch ducts to the hopper were manually adjusted, the flow swing would persist and eventually steam rate would fall, swinging the demand for air back to the maximum levels, the cycle continually repeating.

The implemented modification allowed for independent and automatic flow control of the air distribution to each of the grate hoppers. The flow was continuously adjusted to maintain (1) the desired air proportions to each grate section, and (2) the correct total primary air flow to maintain good combustion and steam flow rate.

c) Overfire Air Supply System Modifications

The 1978 design overfire air system supplied ambient air to the original flue chamber from bull-nose plenum which in turn supplied the multiple secondary air nozzles located in the underside of the front panel of the water-cooled arch. The ambient air was drawn from the refuse storage pit area via the secondary air fan.

The overfire air modification, as shown in Figure 2.5, was made to supply overfire air (secondary air) to the flue gas stream from both the front and rear bull-nose via new multiple nozzle arrangements, in a manner similar to Von Roll's latest design practice.

To achieve the necessary control between the front and rear nozzles, powered isolating dampers and flow controllers (primarily controlled relative to combustion gas boiler inlet temperature) were installed in the respective ducts.

With the modified design, overfire or secondary air is introduced into the furnace by 10 nozzles in the front wall bull-nose and 9 nozzles in the rear wall nose. Ambient air is drawn via the secondary air supply fan, rated at 23,800 m³/h at 500 mm WG.

The nozzles were installed with individual manual dampers for refining adjustment. Each of the front and rear 12.7 cm nozzles were provided with 7.6 cm inserts for greater nozzle flexibility, secondary air penetration and distribution.

The secondary air system was designed to provide a ratio of 3:1 front/rear or rear/front air with a ratio of 65/35 primary/secondary air. The system has the capacity to provide a wide range of ratios to best suit varying operating conditions.

Replacement of the existing secondary air fan with a new unit having a capability of 760 mm WG, to match the highest overfire air pressure reported to date, was considered. However, the design (confirmed by model tests) showed that the nozzle requirement for flow penetration could be met with the existing fan and therefore the high pressure fan concept was dropped.

d) Instrumentation and Control Modifications

In order to bring the Quebec City test unit (#4) up to the "state-of-the-art" in automatic controls, several modifications were made. The major items included the following:

- Modification of the grate hydraulic control system to automatically vary the grate stroke frequency in response to boiler steam flow.

- Incorporation of the excess air (oxygen monitor) feedback to the grate speed controller.

- Modification of the primary airflow controller to automatically respond to steam set-point and/or the excess air level (oxygen monitor).

- Provision of automatic flow control for the primary air distribution system to maintain the desired air proportioning ratios to each hopper zone, including under the drying and finishing grates.

- Provision of a secondary air supply control system to automatically vary the flow rate and the ratio of front/rear air in response to temperature readings in the upper part of the radiation chamber.

Further discussion of the control system is provided under Section 2.9, Control Room and Instrumention.

2.5   WASTE HEAT BOILER SYSTEM

Each waste heat recovery boiler has a rated capacity of 37,000 kg/h at 4690 kpa and 316°C. Each of the four units are typically operated between 27,000 kg/h and 34,000 kg/h, depending on the desired steam rate. Generation rates as high as 45,000 kg/h have apparently been achieved for short periods.

The boiler is a one-drum type, with the tube panels hung vertically, perpendicular to the flue gas flow. Flue gases enter the convection section after the screen tubes, pass through two evaporator tube banks, a superheater tube bank, a third evaporator tube bank and finally an economizer tube bank.

Flue gases from the radiation chamber are normally 850 - 1000°C prior to entering the boiler convection section, although old design temperatures over 1100°C have been reported. With the new design, temperatures are limited by the overfire air system.

A mechanical rapping system is used for tube cleaning. The rapping system consists of revolving hammers attached to a horizontal driving shaft, operating on a timed sequence. The particulates fall into the hoppers below and are conveyed to the quench tank for handling in the ash pit.

Boiler flue gas outlet design temperature is 176°C minimum, 265°C maximum. The minimum temperature level can be reached after manual tube cleaning periods and the maximum, prior to maintenance shutdown under high rate conditions. The normal operating range is 205 - 250°C.

2.6   ELECTROSTATIC PRECIPITATOR

The flue gas exiting from the boiler sections pass into a two-field precipitator via a transition flue and a perforated distribution plate. Original specifications for each of the four precipitators were as follows:

Gas flow: 169,900 m^3/h at 288°C;
Inlet loading: 13.3 kg of particulate/1000 kg of dry gas (50% excess air); and
Outlet loading: 0.2 kg of particulate/1000 kg of dry gas (50% excess air).

The collected fly ash is handled by an air lock system and a bulk flow conveyor system which discharges the fly ash into the quench tank.

2.7   INDUCED DRAFT FAN AND STACK

The flue gases leaving the precipitator are drawn through the double inlet, motor-driven, centrifugal, induced draft (I.D.) fan and discharged into a single flue stack. The induced draft automatically maintains a manual set-point of negative pressure in the incinerator by modulating the damper. The I.D. fan capacity is 240,000 m^3/h at 16.5 cm of water at 250°C.

2.8   ASH HANDLING

Ash residue from the incinerator, including grate siftings and non-burnables is discharged at the end of the finishing grate into a water-filled quench tank below. As indicated previously, fly ash from the waste heat boiler hoppers and from the precipitator hoppers are transferred by bulk flow conveyors and are also discharged into the quench tank.

Ash settles to the bottom of the quench tank and is drawn along the bottom by a heavy duty drag chain conveyor then up an incline to allow water to drain back to the quench tank. The ash discharges off the end of the incline and falls into the ash storage pit below. An overhead bridge/bucket crane transfers the ash to a transport trailer truck which then takes the ash to a designated landfill for disposal.

2.9   CONTROL ROOM AND INSTRUMENTATION

This section describes the process control of Unit #4 only.

General

The existing main analogue control system presently controls three of the four units (#1, #2 and #3) as well as the common services to all four units. Common services in the analogue system include displaying total plant steam, total send-out steam and other parameters.

The new computer control system employed on Unit #4 is a Bailey NETWORK-90, with two colour screens, two control boards, two printers and a datalogging system. Graphic groups can be readily displayed on either screen to inform the operator of any monitored operating condition, both present and past. The graphic groups are detailed in Table 2.1.

TABLE 2.1
CONTROL ROOM GRAPHICS

Group	Title	Displays
A	General	- steam flow/pressure - flue gas temperatures - primary/secondary air flows - primary air flow splits to various grate areas - grate speeds - O_2 level - front/rear secondary air flow split
B	Steam4B, 4C, 4H, 4J -	
	O_2	provide status of process
	Grate Speed	controller or status including operating set-point or gain,
C-G, I	Primary Air	controller signal output and
H	Secondary Air	process operating condition.
J	Temperatures	

Within each of the operating groups, individual controller "sheets" may be displayed providing more specific detailed data with respect to each controller. As well, electronic graph recordings are available for the previous 20-minute process period or groups of 20-minute time periods up to 24 hours. Data are stored on software disks and can be printed on request. In addition, displays of individual controllers provided a graphic presentation of:

- high/low limit set-points;
- the present set-point and present operating condition set-point deviation;

- the controller's auto/manual status;
- percentage of maximum controller output;
- any alarm conditions; and
- steam characteristics.

The process control system installed under the NITEP modification program regulates:

- Steam flow rate,
- Grate speed,
- Primary airflow and distribution,
- Flue gas oxygen level,
- Secondary airflow and distribution, and
- Boiler inlet temperature.

The following sections detail the above control systems.

Steam Flow Rate and Grate Speed Control

The grate speed is paced from the steam flow rate signal when operated in the auto mode. Each grate increases or decreases at a manually preset proportion of its maximum grate speed, thus allowing all three grates to operate at different speeds at any one time.

The grate speed is also integrated with the excess air levels through a proportioning signal, which receives both the excess air and steam flow rate signals and overrides the steam flow rate signal when the preset excess air minimum and maximum limits are reached, at which time the grate speed increases or decreases accordingly.

Primary Airflow and Flue Gas Oxygen Level Control

The total primary airflow is controlled automatically by modulating the primary air distribution dampers in response to the steam flow rate and the oxygen monitor signals. The feedback control from the oxygen monitor results in the reduction of the primary air, should the excess air level rise above the set-point.

The resultant total flow signal is utilized to provide the necessary control signal to each of the individual duct flow controllers below the burning, drying and finishing grates. Thus, the steam flow rate and oxygen monitor signals are utilized to individually modify the amount of air to be delivered to each hopper. This is accomplished by a ratio relay which provides the set-point flow percentage to be maintained to each hopper. While the proportion to each hopper is manually preset, the individual flow sensors modulate the respective primary air supply damper to maintain the desired flow split. If total primary air is signalled to increase, all branch flow rate set points will increase proportionally.

A manual/auto selector is also provided to permit the manual adjustment of each hopper flow control damper by the operator.

Secondary Airflow and Boiler Inlet Temperature Control

Temperature sensors are installed in the front and back of the furnace radiation chamber near the boiler inlet to control the overfire (secondary) air system which, in turn, completes a feedback mechanism which controls the boiler inlet temperature. The ratio of front/rear secondary air can be selected by the operator or controlled automatically by these temperature sensors. The total secondary air supply system can be automatically controlled by the upper or lower temperature sensors, or may be operated at a fixed air supply rate if so desired. In addition, a manually set ratio of primary to secondary air can also be selected with the upper temperature sensor, modifying the actual amount of secondary or overfire air.

3.0   APPROACH TO TESTING

3.1   INTRODUCTION

The Quebec City incinerator field test required two distinct but related areas of research knowledge:

- evaluation of the process performance of the unit; and
- emissions characterization.

The first encompasses refuse handling, combustion and heat recovery. The second relates the implications of process operating conditions to the emissions of particulates, metals and trace organic compounds.

Figure 3.1 presents the project workplan used for the NITEP-Quebec study.

Although much of the basic approach to testing was developed in planning and field testing for the NITEP PEI Program, particularly in terms of the selection of basic sampling methods and protocols, the Quebec City program departed from the first with respect to undertaking furnace design modifications to modernize and to significantly improve the combustion efficiency and facility to control the furnace.

The sampling methods and protocols established for the PEI program were reviewed and testing methods, as described in Chapter 5, were applied to the Quebec City test program.

A particular advantage of the Quebec incinerator over the PEI incinerator was the extensive amount of stack test work that had already been undertaken at the Quebec City facility. The 10-year old Quebec facility had been the subject of acceptance testing, annual testing for particulates, particle size characterization, and testing for HCl and metals emissions, as well as dioxin and furan emission rates, all as part of a provincial monitoring and assessment program. The accumulated emission data provided the background data needed to assess any combustion and emission improvements after the process modification. The new, state-of-the-art furnace design and computer process control system had been installed shortly before the start of the proposed testing.
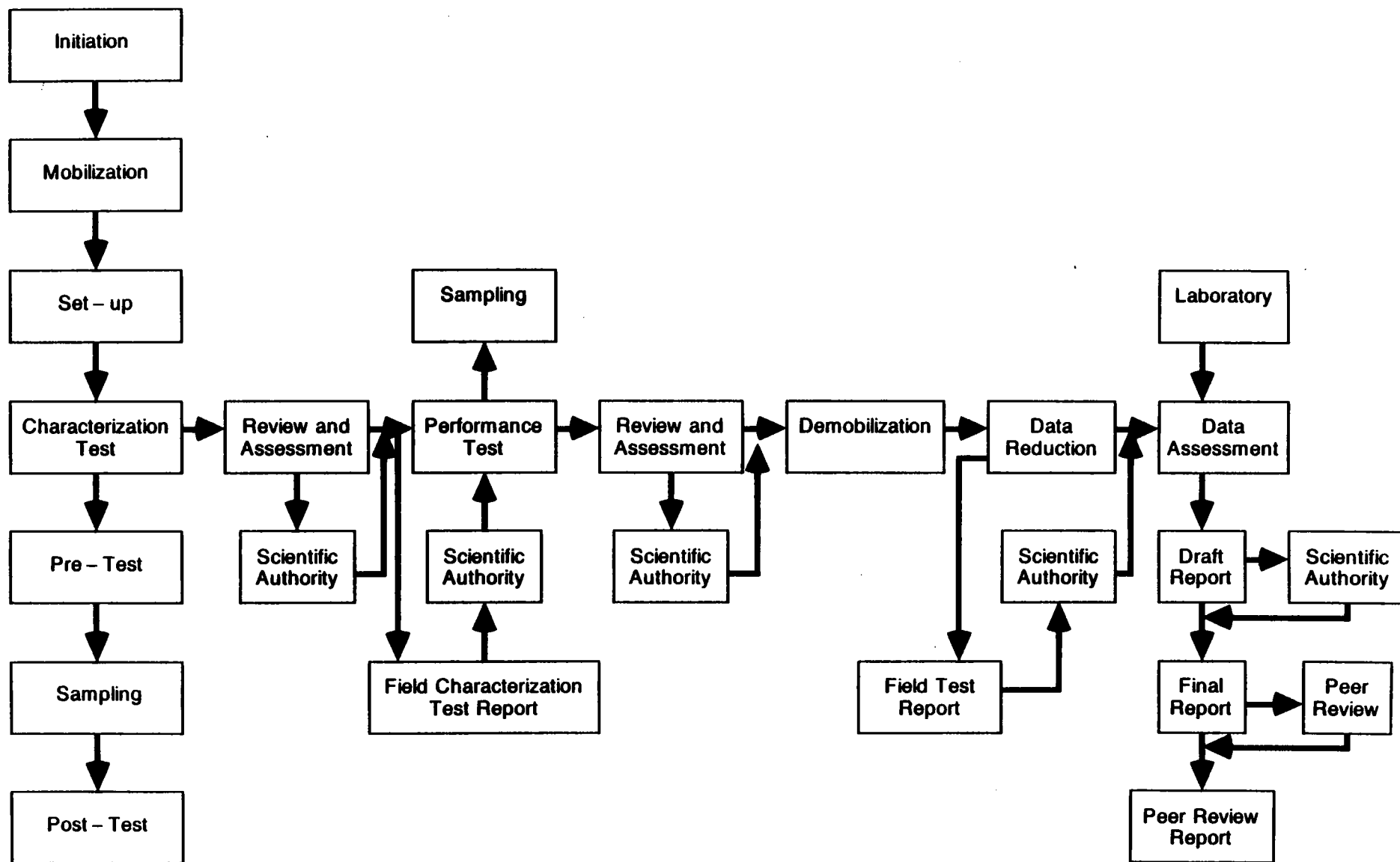
Figure 3.1
QUEBEC INCINERATOR
Diagram of Project Workplan

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3.2   RATIONALE FOR SAMPLING ARRANGEMENT

3.2.1   Selection of the Incinerator Unit for Testing

An important factor in developing the detailed plans for the test program was the selection of the specific test unit. Unit #4 was considered to be the optimal unit and was selected for modernization and testing because of the following advantages:

- a reasonable exhaust gas sampling location (an advantage this unit shared with Unit #1),
- large area available to install the continuous gas monitoring equipment,
- ready access to the open sections of property behind the main building, and
- least interference with the normal operation of the other units.

Unit #4 was upgraded as described in Section 2.4.5.

3.2.2   Selection of Sampling Locations

Sampling locations were selected to obtain all information necessary in the development of an understanding of the unit's operation. Sampling locations finally selected are shown in Figure 3.2 and described below. The sampling procedures are described in Chapter 5.

Refuse

The refuse consumed by Unit #4 during the tests determined the amount of energy available and thus the system performance. This is obviously a very important operating parameter. It was therefore necessary to accurately weigh all refuse fed to the test unit. Provisions were made to record the time and weight of each charge (Location #5).

Since municipal refuse composition and heat content varies significantly with time, representative samples of incoming refuse were collected (Location #4) during each test run.

Radiation Chamber Temperature

The existence of low temperature zones in the furnace and a low retention time are considered by many experts to be most likely responsible for the formation of dioxin and furan and the failure of the system to destruct these organic compounds. In an attempt to determine whether such zones exist,

2 RADIATION CHAMBER AND BOILER INLET TEMPERATURES

3 REFUSE RATE

EXHAUST GAS

CONTINUOUS GAS
TRACE ORGANICS
METALS
PARTICULATES
PARTICLE SIZE
HCl

9

4 REFUSE SAMPLING

8 PRECIPITATOR ASH

7 BOILER ASH

INCINERATOR ASH

6 QUENCH TANK ASH

5 INCINERATOR

1 (COMPUTER ROOM) DATA ACQUISITION SYSTEM
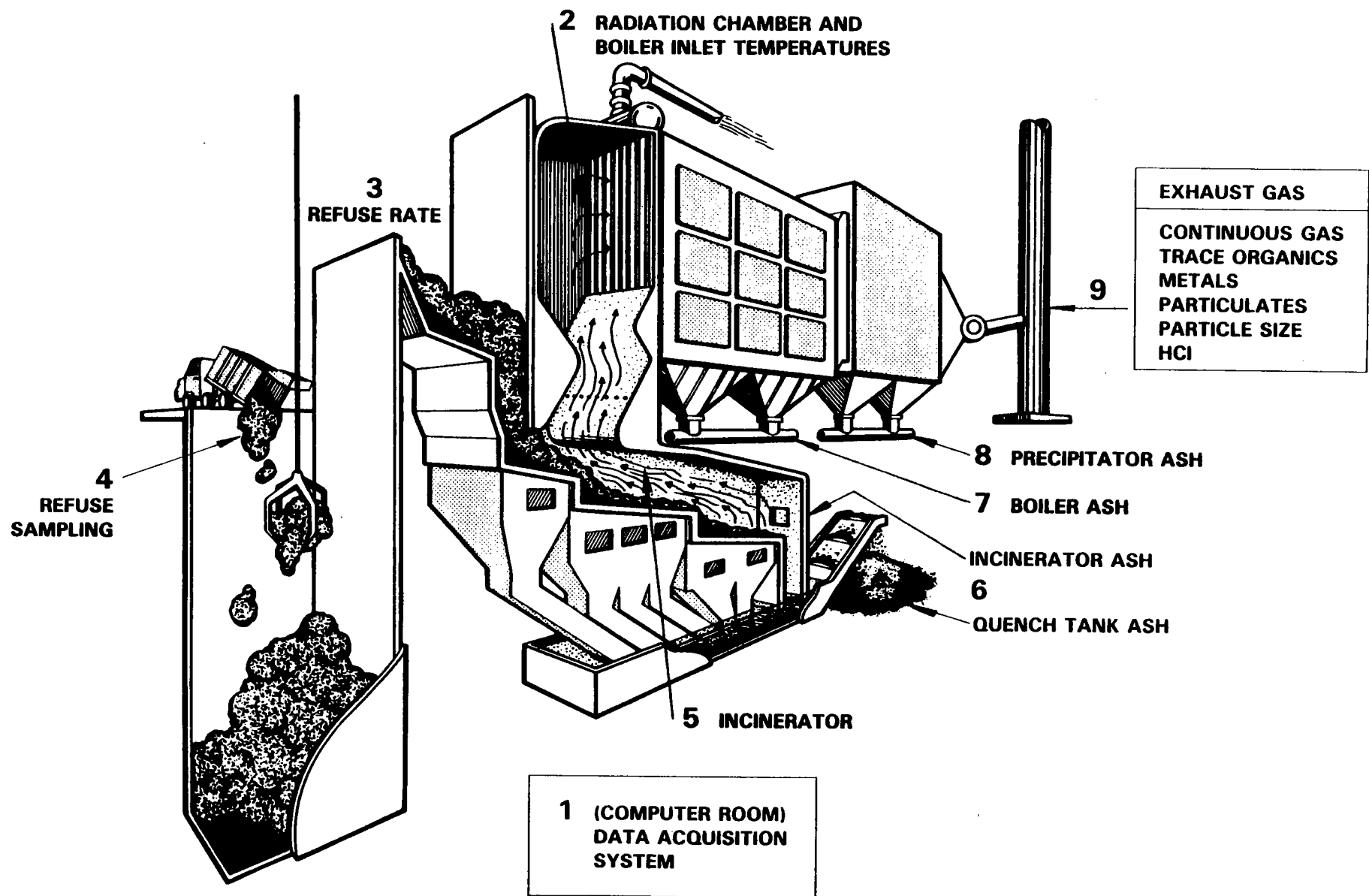
Figure 3.2
QUEBEC INCINERATOR
Sampling Locations

thermocouple grids were installed in the radiation chamber (just above the level of overfire air injection) and at the boiler inlet (Location #2).

Incinerator Ash

Ash quality is used by operators as a primary indicator of satisfactory operation of the incineration process. Ash was sampled directly from the finishing grate through a new opening (installed for NITEP tests) in the rear access door (Location #6).

Quench Tank Ash

To determine the refuse volume and weight reduction achieved by the unit, determination of the total quantity of bottom ash was required. This was ascertained by diverting the boiler/economizer and precipitator ashes from the quench tank and weighing the ash transport vehicle containing the wet quench tank ash which had accumulated in the ash pit during the test period (Location #6). Weighing was carried out using the plant's main truck scales. Ash was also sampled directly from the truck to provide data on the water content of the ash.

Boiler/Economizer Ash

Modification of the ash chute from the heat recovery boiler was made in order to collect all ash from the boiler/economizer hoppers. No attempt was made to separate the boiler ash from the economizer ash, because of the physical location of the hoppers, the high cost and the low priority to the program objectives. This sampling location was designated as #7.

Electrostatic Precipitator Ash

Precipitator ash quantity and colour provide a first order indication of the unit efficiency and act as primary indicators for the exhaust gas particulate emission. Thus, all the electrostatic precipitator ash was collected and sampled. This location was designated as #8.

Combustion Gas Sampling

Incinerator exhaust gases and subsequent emissions to the environment pass through a common breeching (shared with Unit #3) and up the stack where they combine with exhaust gases from the other two units. The vertical and horizontal flue sections at the induced draft (ID) fan exhaust were the only acceptable locations available for sampling Unit #4 exhaust. Extensive stratification tests were made at the horizontal sampling location to determine if there was any significant gaseous or particulate stratification, as detailed in Section 9.6. Continuous gas samples were extracted from a high turbulence zone in the vertical duct section, while organics, particle sizing, heavy metals, mercury,

and acid gas samples were extracted from the horizontal section of the duct. The exhaust gases platform was designated Location #9.

Data Acquisition

All process, continuous gas data and temperatures were monitored on a continuous basis throughout the tests, as discussed in Sections 5.6 and 5.7. This was achieved by connecting the Bailey Network-90 process control system and dataloggers with an integrated personal computer data handling system. Relevant process data were gathered, recorded and displayed on a real-time basis. (Location #1). Overnight, 5-minute averages for all parameters were calculated with maximum and minimum values shown.

3.3   CHARACTERIZATION TESTING

3.3.1   Objectives

The purpose of the Characterization Test runs was to familiarize the test crew with the test incinerator, to implement and refine the data handling and sampling systems, and to assess the operating capabilities of the incinerator to define an optimum Performance Test matrix.

Experience on similar projects has shown that Characterization testing or preliminary testing, is a necessary prerequisite to define acceptable process test conditions and to de-bug the test procedures prior to the formal and more costly Performance Tests. In addition, Characterization Tests have proven to be an excellent mechanism for the determination of process capabilities and limitations.

The duration and extent of testing were always tailored to suit the process parameter under consideration. To complete as many trials as possible, the sampling time for the Characterization Tests was limited to a maximum of 2.5 hours. Due to the preliminary nature of these tests only a few manual stack sampling trains were operated during the Characterization phase (i.e., heavy metals, organics, etc.) to assess contaminant levels and sampling location suitability (CT-14 and CT-15).

All process parameter and continuous gas analyzer data were continuously monitored prior to, during, and after both the Characterization and Performance Test periods. These results were employed to assist field personnel in establishing the effects on emissions due to operating changes, and also, to ensure that short-term fluctuations did not misrepresent the character of the particular operating mode at the time. Figure 3.3 shows the parameters investigated during the Characterization Tests.

The Characterization Tests essentially involved changing only one process parameter under constant operating conditions to identify how the unit would respond and how each parameter effected the

Steam   Temperature   Combustion Air

Process

• Feed Rate — Refuse — Input — **Incinerator** — Output — Particulate

Continuous Gas
- CO
- CO_2
- O_2
- NO_x
- HC
- HCl
- SO_2

Ash

Incinerator   Boiler   Precipitator

- Feed Rate
- Combustibles
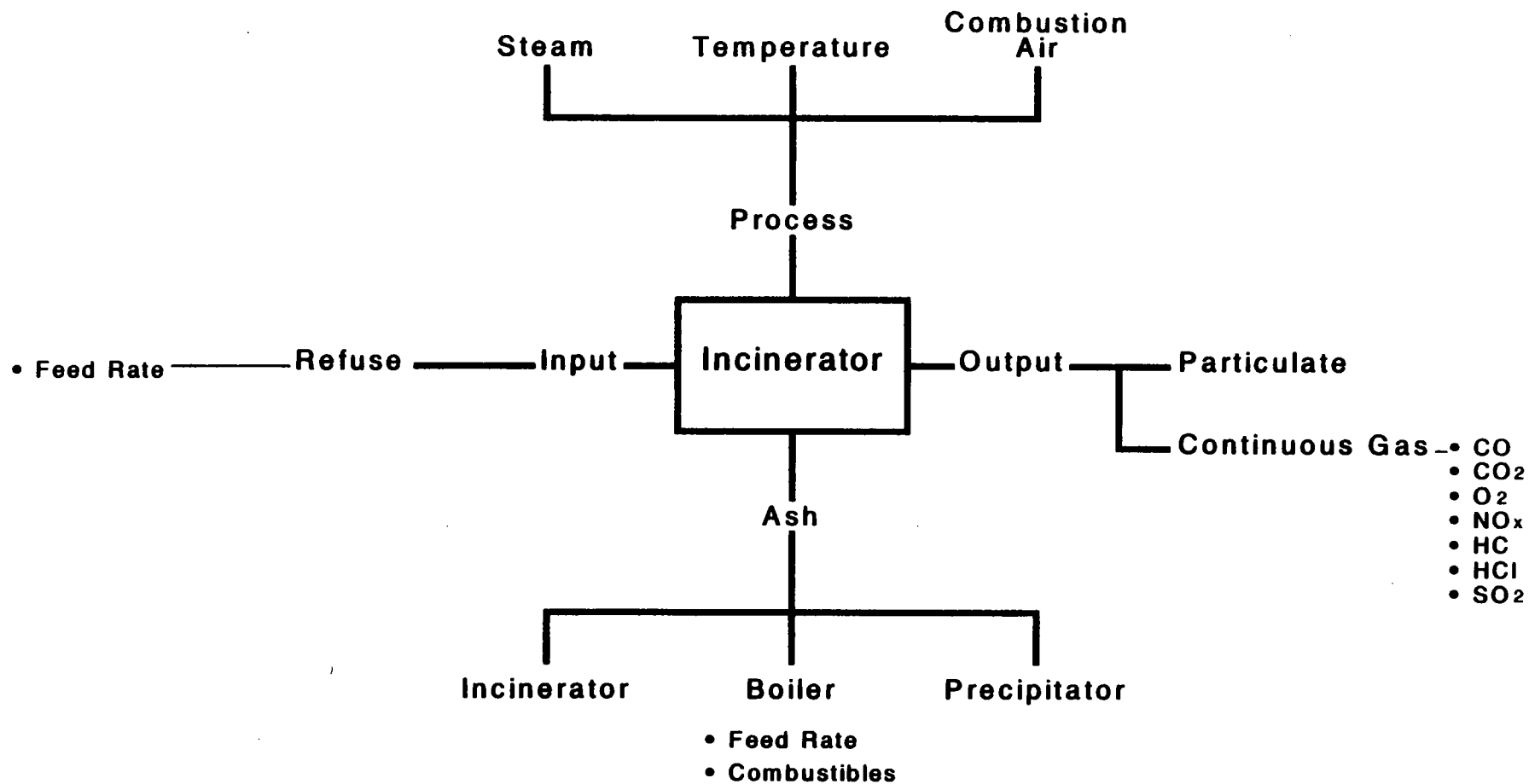
Figure 3.3
QUEBEC INCINERATOR
Characterization Test Parameters

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overall performance of the unit. For a more complete explanation of the Characterization Test development work refer to Chapter 9.0.

The results of the Characterization Tests were discussed with the Scientific Authority (SA) and the owner/operator to determine which test conditions should be performed during the more comprehensive Performance Tests.

Since only a limited number of conditions were available for testing, a hierarchy of process parameters was established to ensure that information for the most critical parameter effecting the overall operation would be surely obtained, leaving the less critical parameters for last. Specifically, each set-point or range of the succeeding (less critical) parameter would be tested at each defined set-point of the preceding (more critical) parameter. Set-points or ranges were defined for each parameter to encompass the desired operating range.

The process parameters considered during the Characterization Tests and the order in which these parameters were optimized is as follows:

1) Refuse Feed Rate/Steam Rate,
2) Excess Air,
3) Primary/Secondary Air Split,
4) Primary Air Hopper Split,
5) Burning Grate Refuse Depth,
6) Finishing Grate Ash Depth,
7) Front/Rear Secondary Air Ratio, and
8) Vertical Flue Front/Rear Temperature Control.

Originally 34 test conditions were considered during the Characterization program. However, varying some of the process parameters resulted in the elimination of some non-testworthy control set-points. These experimental process variations were performed during the initial familiarization period and at the conclusion of each test day, in preparation for the next day's test. As a result, the original 34 test conditions were reduced down to 19. Many of the eliminated test conditions were deemed unsuitable for the following reasons:

● the process could not be held at this condition for an extended period, due to the radical set-points initially selected;

● from simple visual interpretation of the burning process it was revealed that excessive burn-bed particulate "lift-off", slagging, over temperature, and other conditions where damage to equipment may result, were obviously unacceptable combustion conditions.

Overall the nineteen Characterization Tests completed were considered sufficient to demonstrate how the unit's performance changed under the various operating modes.

Three waste feed rates were chosen: low, design and high. For each feed rate, both low and high excess air rate conditions were selected. An attempt was also made at each excess air condition to operate at low and high radiation chamber temperatures as shown in Figure 3.4. However, some temperature condition goals were not considered feasible due to the quality of the refuse at the time and/or simply the fact that the attempted condition was impractical.

The end result was a set of tests representing a good cross-section of test-worthy operating conditions.

3.3.2   Process Parameters

Daily site meetings were held with the SA and the operator to discuss the proposed Characterization Test runs. Particular attention was paid to time requirements and details of adjustments necessary to achieve the desired operating conditions. Immediately prior to each Characterization Test run, operating conditions were closely observed and monitored to ensure that the unit had stabilized.

Key process parameters monitored during the Characterization Tests included:

a)   Feed Rate/Steam Rate

As a consequence of a lower refuse calorific value than originally designed, the normal refuse feed rate is routinely greater than the original design throughput rate of 227 tpd; the steam rate is routinely less than the original design rate of 37 tonnes/hour. For the Characterization Tests, the unit was operated at a low rate of 20 tonnes/hour steam, the modified design rate of 28 tonnes/hour steam, and a high rate of 32 tonnes/hour steam.

b)   Underfire (Primary) Air Distribution

Modifications made to the undergrate hoppers and control systems provided improved of air distribution under the grates, thereby permitting greater flexibility in the air distribution during testing. Several tests investigated different air distribution patterns to the burning and finishing grates, again to determine the effect on performance and to identify the preferred distribution for the Performance Tests.

c)   Primary/Secondary Air Ratio

Primary (underfire) airflow and grate speed are paced on steam flow; feedback control on the primary air and grate speed is provided by the oxygen analyzer. Several tests at various oxygen levels and primary/secondary air ratios were undertaken to gain an appreciation of the effects of each on the performance of the unit and to identify the preferred settings for the Performance Test phase.

Feed Rate: Low   Design   High

Excess Air Rate:

	Low		High		Low			High			Low			High	

Radiation Chamber Temperature	Low	High	Low	High	Low	High	Very Low	Low	High	Low	High	Very High	Low	Medium	High
Characterization Tests	CTØ1	CTØ2	CT18, CT19	*	CTØ3, CTØ4, CTØ8	CT11, CT16	CTØ7	CT17	CT12	*	CTØ6, CTØ9	CT15	CTØ5	CT1Ø	CT13, CT14

* under the feed rate and excess air rate conditions, the desired temperature could not be attained

Figure 3.4
QUEBEC INCINERATOR
Characterization Test Operating Models

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d) Boiler Inlet Temperature

Several tests at low and high radiation chamber temperatures were made to gain an appreciation for the effect of excess air and primary/secondary air ratios on combustion efficiency, boiler efficiency, and particulate carryover.

Based on the aforementioned findings, a systematic Characterization plan was developed. The objectives were to achieve the maximum number of runs for a representative range of operating conditions in the short period of time available. The resulting Characterization Test matrix, is illustrated in Figure 3.4.

3.3.3   Sampling Parameters

Prior to each Characterization Test run, the following pre-test checks were made:

- Exhaust gas continuous analyzer systems were leak-checked and each analyzer was calibrated and zeroed;

- Weigh scales were calibrated and zeroed; and

- Equipment was verified as operating satisfactorily.

Details of the parameters monitored and/or tested during each Characterization Test run are listed in Table 3.2 and shown graphically in Figure 3.5.

Ash sampling was limited to only a few tests to assess the adequacy of the collection systems. Detailed assessments were also made of the incinerator, boiler/economizer, and precipitator ash collection systems necessitating modifications, as described in Chapter 4.0, to obtain representative samples.

As part of the field evaluations, assessment of the ash quality was made primarily by direct expert observations and quantity. Ash quantity was evaluated by measuring the ash rate.

The parameters that were continuously monitored, included the following:

- process data from the computer control system including steam rate, grate speeds, and combustion air rates;

- radiation chamber and boiler inlet temperatures;

- flue gas temperatures and flows;

- plant opacity monitor; and

- exhaust gas data from the continuous emission monitors (CO_2, CO, O_2, NO_x, SO_2, HCl, THC).

TABLE 3.1

SUMMARY OF CHARACTERIZATION SAMPLING AND TEST PARAMETERS

Sampling Location	Monitored/Sampled Parameter	Monitored/Analyzed Components	Frequency	Protocol Section
Refuse	Feedrate		Each Charge	5.2
Incinerator	Observations Temperature Various Zone Temperature		Every 15 min. Continuous Continuous	5.3
Primary Air	Temperature Flow, Relative Humidity (RH)		Continuous Continuous Continuous	5.3
Secondary Air	Temperature Flow		Continuous Continuous	5.3
Boiler Ash	Mass Rate		Integrated	5.4
Precipitator Ash	Mass Rate		Integrated	5.4
Exhaust Gas	Combustion Gases Trace Gases Particulate Loading	CO, CO2, O2 THC, SO2, NO-NOx, HCl	Continuous Continuous Integrated	5.5
Boiler Inlet	Temperature		Continuous	5.3
Process Data	Computer Process Control		Continuous	5.6
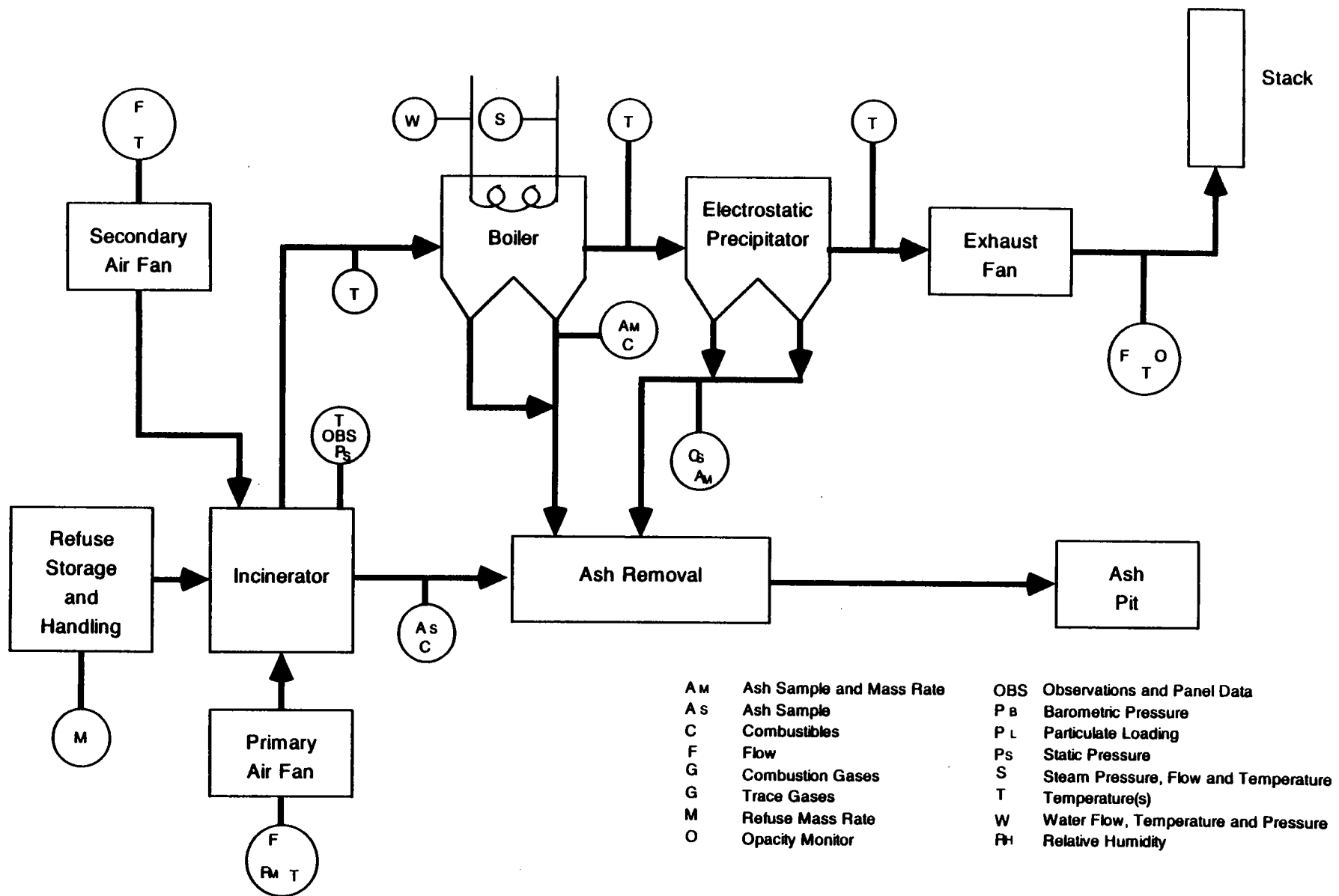
Figure 3.5
QUEBEC INCINERATOR
Process Schematic for Characterization Tests

A M	Ash Sample and Mass Rate	OBS	Observations and Panel Data
A s	Ash Sample	P B	Barometric Pressure
C	Combustibles	P L	Particulate Loading
F	Flow	Ps	Static Pressure
G	Combustion Gases	S	Steam Pressure, Flow and Temperature
G	Trace Gases	T	Temperature(s)
M	Refuse Mass Rate	W	Water Flow, Temperature and Pressure
O	Opacity Monitor	RH	Relative Humidity

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Refuse feedrate measurements commenced at least half an hour prior to each Characterization run and ash sampling continued for at least half an hour after the end of a run. The extra half hour at the beginning and the end of a run was to compensate for the approximate residence time of refuse travelling on the incinerator grate. Large unburnables, such as steel water tanks, were periodically introduced into the refuse feed system to provide an approximate indication of the materials transport time under various feed rates.

The results of the Characterization Tests are discussed in Chapter 9.

3.3.4 Stratification Test

The horizontal flue gas sampling location available was not ideal, with 3 equivalent duct diameters between the first set of ports and duct elbows, and 1.6 equivalent duct diameters between the last set of ports and the duct enlargements.

To ensure the adequacy of this location for exhaust gas sampling of particulates and organics, stratification tests were performed during CT-14 and CT-15. From our findings it was determined that the sampling location was acceptable. Details of the procedures and results are presented in Sections 5.5.1 and 9.6.

3.4 PERFORMANCE TESTING

3.4.1 Objectives

The purpose of the Performance Tests was to relate operating conditions with emissions of trace metals and trace organics, ash quality, and boiler efficiency. The Performance Test parameters sampled and monitored, are shown in Figure 3.6.

The results of the Characterization Tests were used to select the five (5) operating conditions for the Performance Test (PT) matrix, as shown in Figure 3.7. The rationale for selection of these 5 Performance Test conditions is discussed in Chapter 9.

The set of operating modes were selected to obtain test results under both good and poor operating conditions for the three burning rates. The operating modes were established primarily by varying the steam rate set-point and the primary (underfire) air and secondary (overfire) air rates. These various operating modes resulted in differing combustion temperatures, levels of oxygen (O_2), and carbon monoxide (CO).
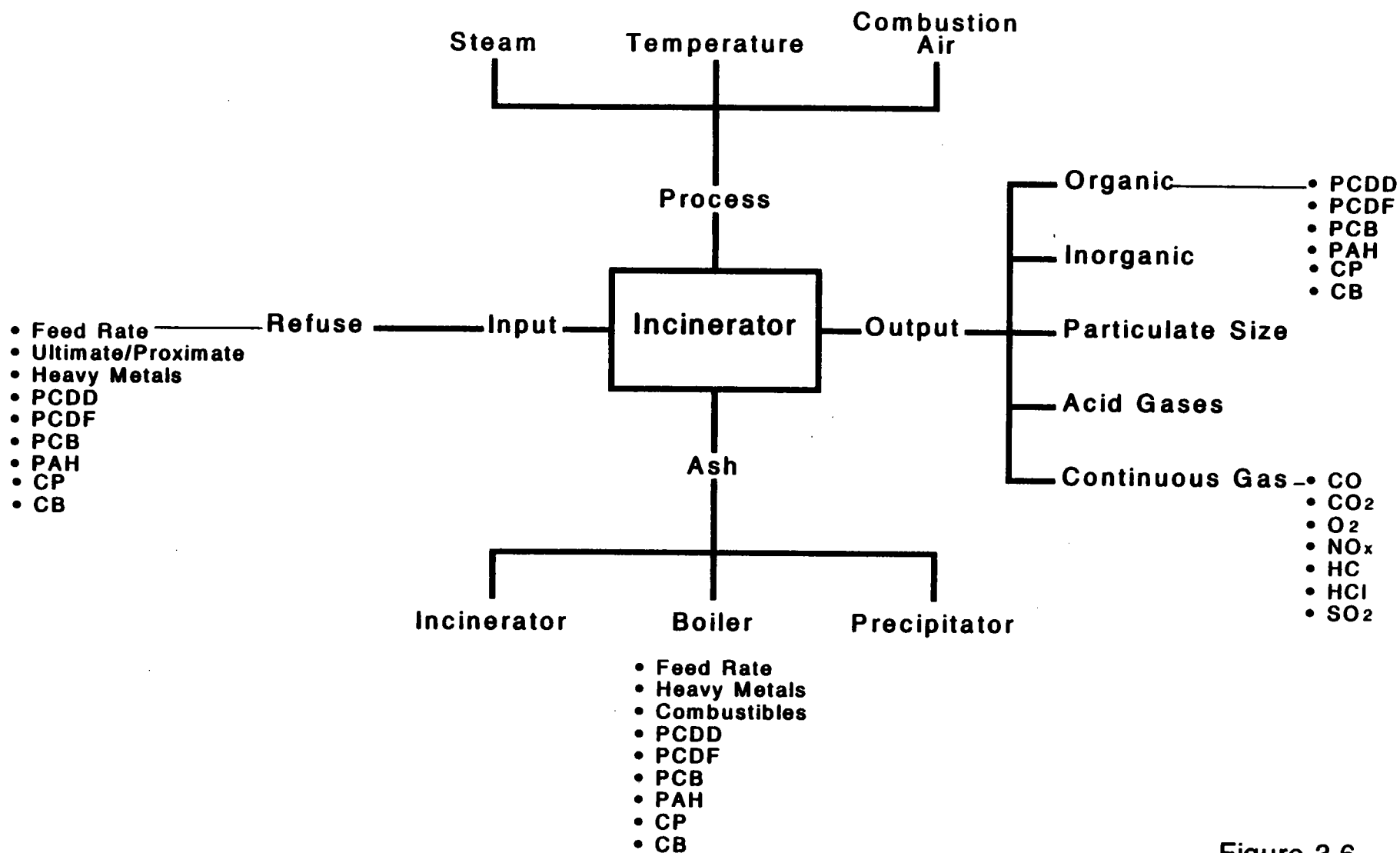
Figure 3.6
QUEBEC INCINERATOR
Performance Test Parameters

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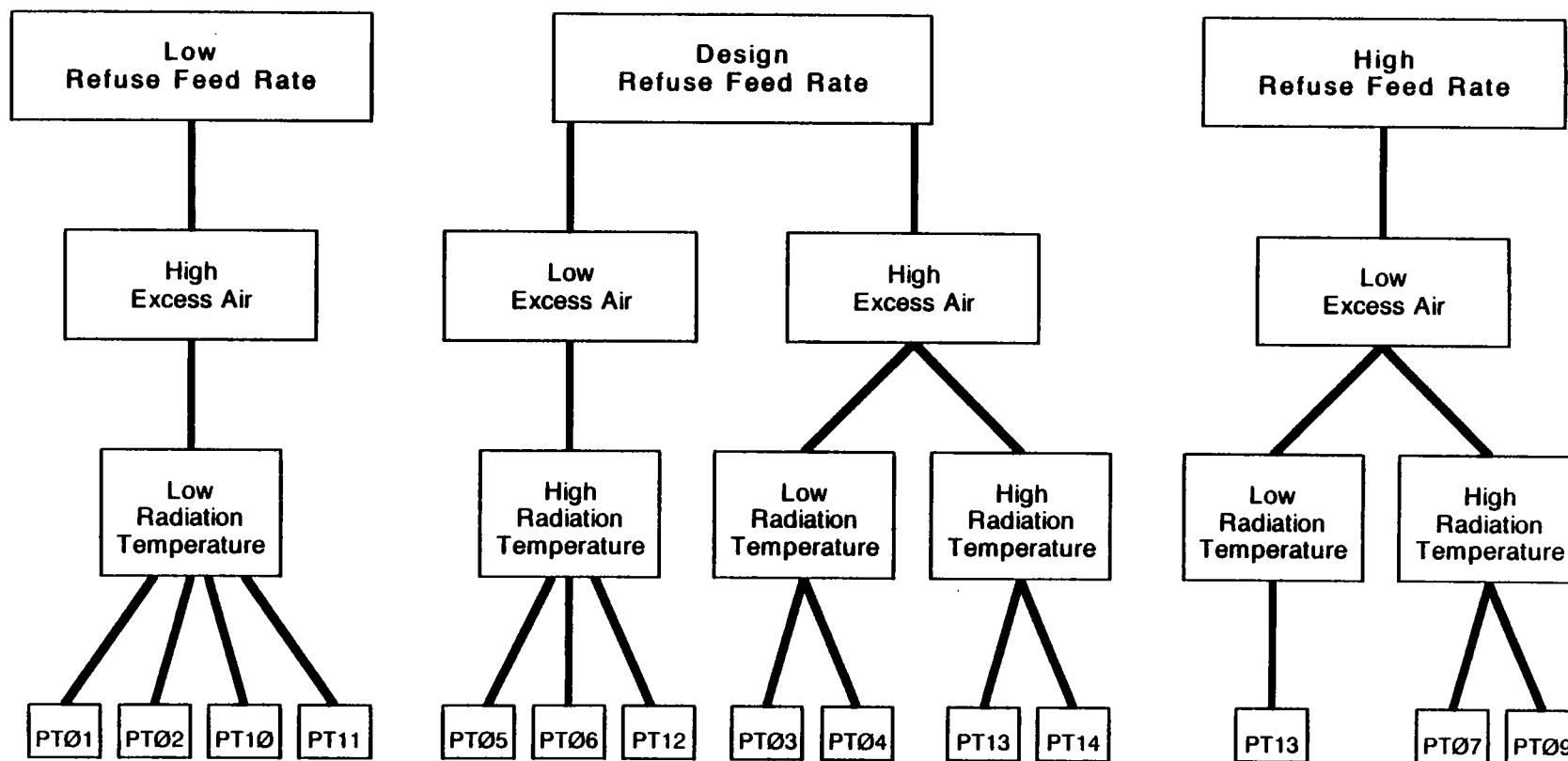
Figure 3.7
QUEBEC INCINERATOR
Performance Test Operating Modes

43138

Replication of tests at the selected operating conditions was devised to assess the repeatability of the unit's performance under the same operating conditions and to examine the accuracies of the individual sampling results. The decision to undertake triplicate tests for the most important operating conditions, and at least duplicate tests for the remaining operating conditions was consistent with the matrix undertaken during the NITEP PEI program and was considered to represent the preferred approach for the Quebec Program.

Before initiating each Performance Test, critical data from the previous test were processed, assembled, summarized and reviewed with the Scientific Authority. These procedures were made possible by the high level of sophistication of the data acquisition and processing system.

Each Performance Test run involved a minimum of ten (10) hours of operation, over and above the time required to bring the unit to steady-state condition before each Performance run was started. A ten-hour test duration allowed a minimum of four hours sampling.

3.4.2 Process Parameters

As stated previously, the testing process parameters or operating modes, were selected based on the unit's performance under both good and poor operating conditions for the three burning rates. Essentially, steam rate set-point, primary air rate, and secondary air rate were varied, resulting in altered levels of O_2, CO, and combustion temperatures.

Immediately after the completion of a PT run, there followed a period during which changes were made to the fuel feed, combustion air rates and operating temperature conditions in preparation for the next day's test set-up. These settings were then held overnight to assist the operators in establishing an operating equilibrium before the next day's run. Determination of whether equilibrium conditions were achieved prior to testing was based on:

- steam rate and furnace temperature fluctuation, visual observations of ash quality, and burning conditions on the grates; and

- continuous gas monitoring levels and variations, particularly CO and O_2.

In general, it required approximately two hours prior to a PT start to confirm that all elements of the test program were ready and that stable test conditions were established.

3.4.3 Sampling Parameters

Sampling locations, parameters, and components for the Performance Tests are summarized in Table 3.4 and shown schematically in Figure 3.8.

TABLE 3.2

SUMMARY OF PERFORMANCE TEST SAMPLING AND PARAMETERS

Sampling Location	Monitored/Sampled Parameter	Monitored/Analyzed Components	Frequency	Protocol Section
Refuse	Feedrate		Each Charge	5.2
	Representative Sample	A) Ultimate/Proximate analyses, HHV B) Metals C) Dioxin, Furan, PCB, PAH, CB, CP	Composited for analysis	
Incinerator	Visual Observations Temperature Pressure		Every 15 min. Continuous Continuous	5.3
Primary Air	Temperature, Pressure Flow, Relative Humidity (RH)		Continuous Continuous Continuous	5.3
Secondary Air	Temperature, Pressure Flow		Continuous Continuous	5.3
Incinerator Ash	Mass Rate		Integrated	5.4
	Representative Sample	A) Combustibles B) Metals C) Dioxin, Furan, PCB, PAH, CB, CP	Every 15 min. Composited for Analysis	
Boiler Ash	Mass Rate		Integrated	5.4
	Representative Sample	A) Combustibles, Particle size B) Metals C) Dioxin, Furan, PCB, PAH, CB, CP	Every 15 min. Composited for Analysis	
Precipitator Ash	Mass Rate		Integrated	5.4
	Representative Sample	A) Combustibles, Particle Size B) Metals C) Dioxin, Furan, PCB, PA , CB, CP	Every 15 min. Composited for analysis	

TABLE 3.2 cont.

SUMMARY OF PERFORMANCE TEST SAMPLING AND PARAMETERS

Sampling Location	Monitored/Sampled Parameter	Monitored/Analyzed Components	Frequency	Protocol Section
Exhaust Gas	Combustion Gases Trace Gases	CO, CO2, O2 THC, SO2, NO-NOx, HCl	Continuous Continuous	5.5
	Particulate Train	Concentration, Mass, Flow, Temperature, Metals, Pressure, Moisture	Integrated	
	Mercury Train	Hg	Integrated	
	Particulate Size Train	Particulate Size Distribution, HCl	Integrated	
	Chlor. Organic Train	Dioxins, Furans, PCB, PAH, Chlorophenols	Integrated	
	Temperature, Flow		Continuous	
Boiler Inlet	Temperature		Continuous	5.3
Precipitator Inlet	Temperature Precipitator Power		Continuous Every Test	5.3
Process Data	Computer Process Control		Continuous	5.6

Stack

Secondary Air Fan

F
T

W   S   T   T

Boiler

Electrostatic Precipitator

Exhaust Fan

T

T

Ps
CA   GA   T
GC   GT   PL
F   O   PD
MO

Refuse Storage and Handling

Incinerator

T
OBS
Ps

AM
C

Ash Removal

AM
C

Ash Pit

R

AM
C

Primary Air Fan

F   Ps
RM   T

A M	Ash Sample and Mass Rate	P B	Barometric Pressure
C	Combustibles	P D	Particle Size Distribution
CA	Chlor, Organics	PL	Particulate Loading Moisture
Fw	Water	Ps	Static Pressure
F	Flow	R	Refuse Sampling and Mass Rate
GA	Acid Gases (HCl)	RH	Relative Humidity
GC	Combustion Gases	S	Steam Pressure, Flow and Temperature
GT	Trace Gases	T	Temperature
O	Opacity Monitor	M O	Moisture
OBS	Observations and Panel Data	W	Water Flow, Temperature and Pressure

Figure 3.8
QUEBEC INCINERATOR
Process Schematic for Performance Tests

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The process and flue gas data collected during the Performance Tests included the following:

- refuse feedrate; ultimate and proximate analysis and higher heating value (HHV) on a representative refuse feed sample;

- primary and secondary airflow distribution, totals and temperature;

- combustible analyses of representative ash samples and mass flow rates from the incinerator, boiler/economizer and precipitator;

- representative flue gas temperature at the boiler inlet;

- representative flue gas temperature and flow leaving the precipitator;

- flue gas composition leaving the precipitator, including CO_2, O_2, CO, NO_x, SO_x, HCl;

- ambient relative humidity and barometric pressure;

- steam and feedwater rates, temperatures and pressures;

- detailed, routine furnace observations by a qualified expert; and

- other relevant process data such as grate speed and control set-points.

The following data gathering was considered very important in assessing the incinerator performance and to determine possible mechanisms for the formation and destruction of organic chemicals, particularly chlorinated aromatics :

- analysis of dioxins, furans, PCB's, PAH's, CB's, CP's and metals in representative refuse, incinerator ash, boiler/ economizer ash and precipitator ash samples; and

- concentrations of dioxins, furans, PCB's, PAH's, CB's, CP's, total particulates, water content, particle size distribution, and metals in the exhaust gases.

4.0 PLANT MODIFICATIONS FOR TESTING

Although a number of stack tests have been undertaken on the Quebec incinerator under the supervision of the Quebec provincial government, the additional requirements of the NITEP test program necessitated considerable site modifications in addition to the major design modernization that was discussed in Section 2.4.

Table 4.1 briefly summarizes the major modifications implemented to prepare the site for the test work. The sampling protocols are described in Chapter 5.

4.1 REFUSE

4.1.1 Refuse Sampling

To prepare a homogeneous refuse sample, a low speed 40-hp shear shredder was installed on the tipping floor of the truck unloading bay to shred the refuse as-received to a size of 2 cm square. To mix the refuse collected on the tipping floor and charge the refuse into the shredder a one-tonne front end loader was employed . A scale was installed to weigh the samples and rejects such as large appliances. To permit cleaning of the shredder and the sampling floor area between each test a steam outlet was also installed at this location.

4.1.2 Refuse Charging Rate

To determine the refuse charging rate, a specially designed weigh scale platform was fabricated and installed. The crane bucket was weighed before each charge was fed into the hopper. Four load cells, fitted underneath the platform, were installed at floor level, adjacent to the Unit #4 feed hopper. Each load cell was rated at 5 tonnes. An inclined platform skirt was installed between the floor and the edge of the steel platform for protection of the scale.

TABLE 4.1

SUMMARY OF PLANT MODIFICATIONS

Item No.	Location	No.	Description
1	Refuse	1	Installation of a 40 hp shear shredder
2		1	Low pressure steam outlet
3		1	20 tonnes scale
4	Radiation Chamber	4	100 mm 4 bolt flanged ports on the 2 observation doors on each side of the unit (Figure 4.1)
5		4	100 mm 4 bolt flanged ports located symetrically below the bottom of the water wall (Figure 4.1)
6		2	100 mm 4 bolt flanged ports on the wall in the boiler section just under the screen tubes on each side of the unit (Figure 4.1)
7		1	25mm low pressure steam outlet
8	Ash	1	Opening in the back door of the incinerator
9		1	Boiler/economizer ash chute modification
10		1	Precipitator ash conveyor modification
11	Exhaust Gas	5 8 2	100 mm ports (Figure 4.2) 150 mm ports (Figure 4.2) 50 mm ports (Figure 4.2)
12		1	3 m x 8.2 m platform with adequate safety railings and access to all ports
13		8	110 VAC x 15 amp. outlets at the level of the F.D. Fan
14		1	Fresh air supply fan at the sampling platform level
15	Process	1	Installation of a computer interface on the Bailey Network-90
16	Facilities	3	14 m trailer
17		1	25 kV transformer
18		2	Bell Canada telephone service

4.2   RADIATION CHAMBER TEMPERATURE

4.2.1   Radiation Chamber

To determine the temperature profile in the radiation chamber, two flange ports were installed on the west side wall and two on the front (north) wall of the radiation chamber below the boiler inlet as shown in Figure 4.1. These ports were used to install the thermocouple probe assembly to measure the radiation temperature above the overfire air ports across a horizontal plane.

Four thermocouple probe support tubes were fabricated of stainless steel pipe 5 cm in diameter, schedule 40. A total of 34 type "K" thermocouples were passed through the insides of the pipes, positioned at drilled openings in the pipes every 45.7 cm. The pipes were cooled by injection of low pressure steam which was released via the probe openings into the furnace.

4.2.2   Boiler Inlet

To measure and identify variations in the temperature of the flue gas entering the boiler, a 15.2 cm port was installed at the base of the screen tube on the boiler side, as shown in Figure 4.1. Twenty (20) stainless steel thermocouples of type "K" were attached to the back of four of the eight boiler inlet screen tubes, every 87 cm.

4.3   ASH SAMPLING

4.3.1   Incinerator Ash

To collect ash samples directly from the finishing grate, a special airlock system was fabricated and installed on the back door of the incinerator, as shown in Figure 4.2. This system allowed the insertion of a stainless steel shovel (20.3 x 25.4 cm) into the furnace with minimum air infiltration during sampling. The system operated such that with Door 1 opened, the shovel could be inserted into the chamber between both doors. Door 1 was then closed (a slotted opening was made in Door 1, the diameter of the shovel handle) and Door 2 to the furnace was opened for insertion of the shovel onto the grate for sample collection. The shovel was then returned to the chamber and after ensuring that Door 2 was closed, Door 1 was re-opened, the shovel was removed and the sample discharged into the container.

Ports

Boiler

Refuse
Feed

Secondary
Air

Drying
Grate

Burning
Grate

Finishing
Grate
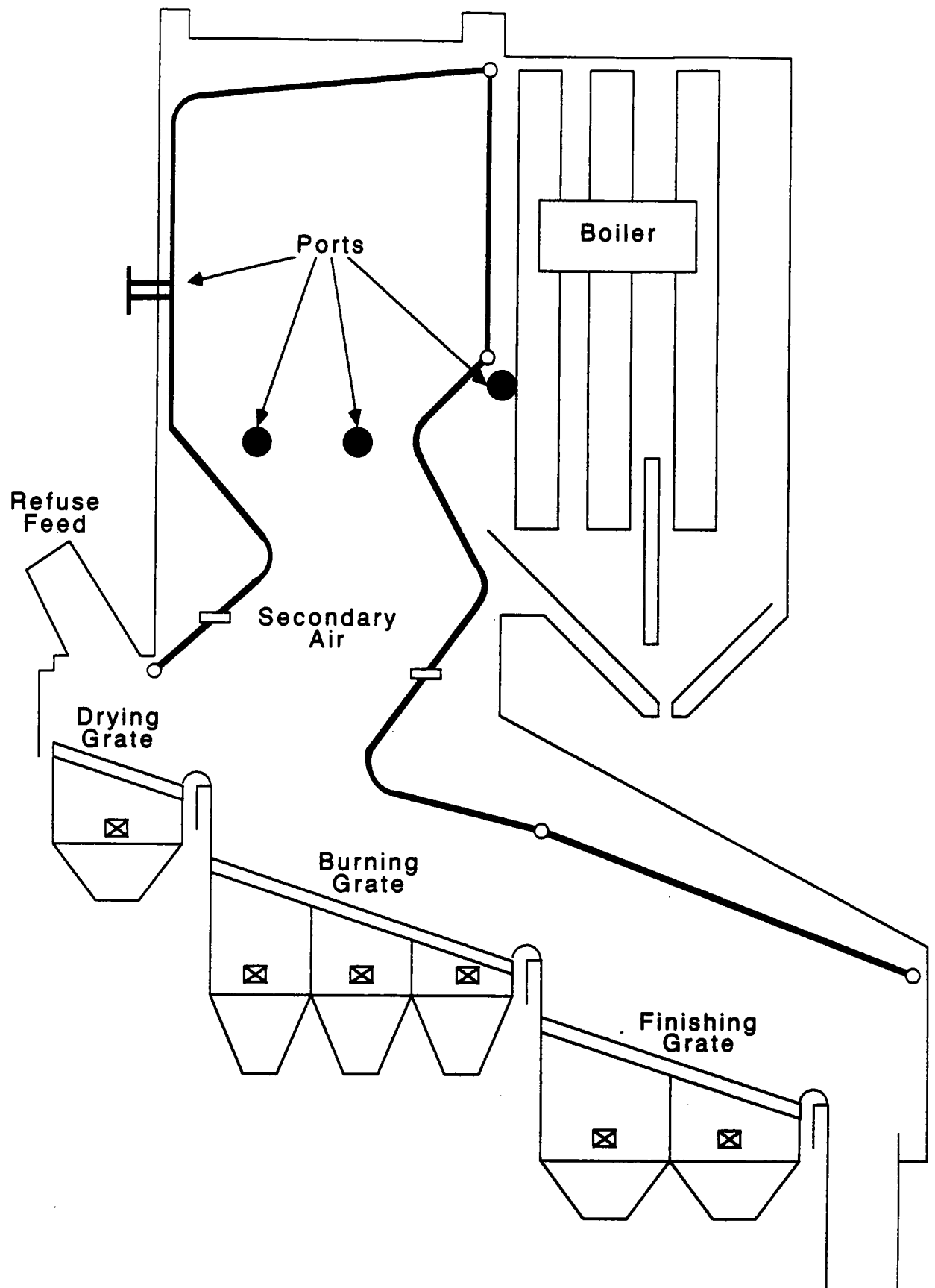
Figure 4.1

QUEBEC INCINERATOR
1986 Modernized Design

43138

Furnace
View
Opening

6 1/2"

Ash

10 1/2"

Door Opening

Light Insulation 3" – 6"

Steel Door
on Hinge

High Temperature
Glass

Steel Door on
Hinge or Slide

Back Door
with Opening
for Pipe

Ash Cooling
Chamber

2 1/4" Steel
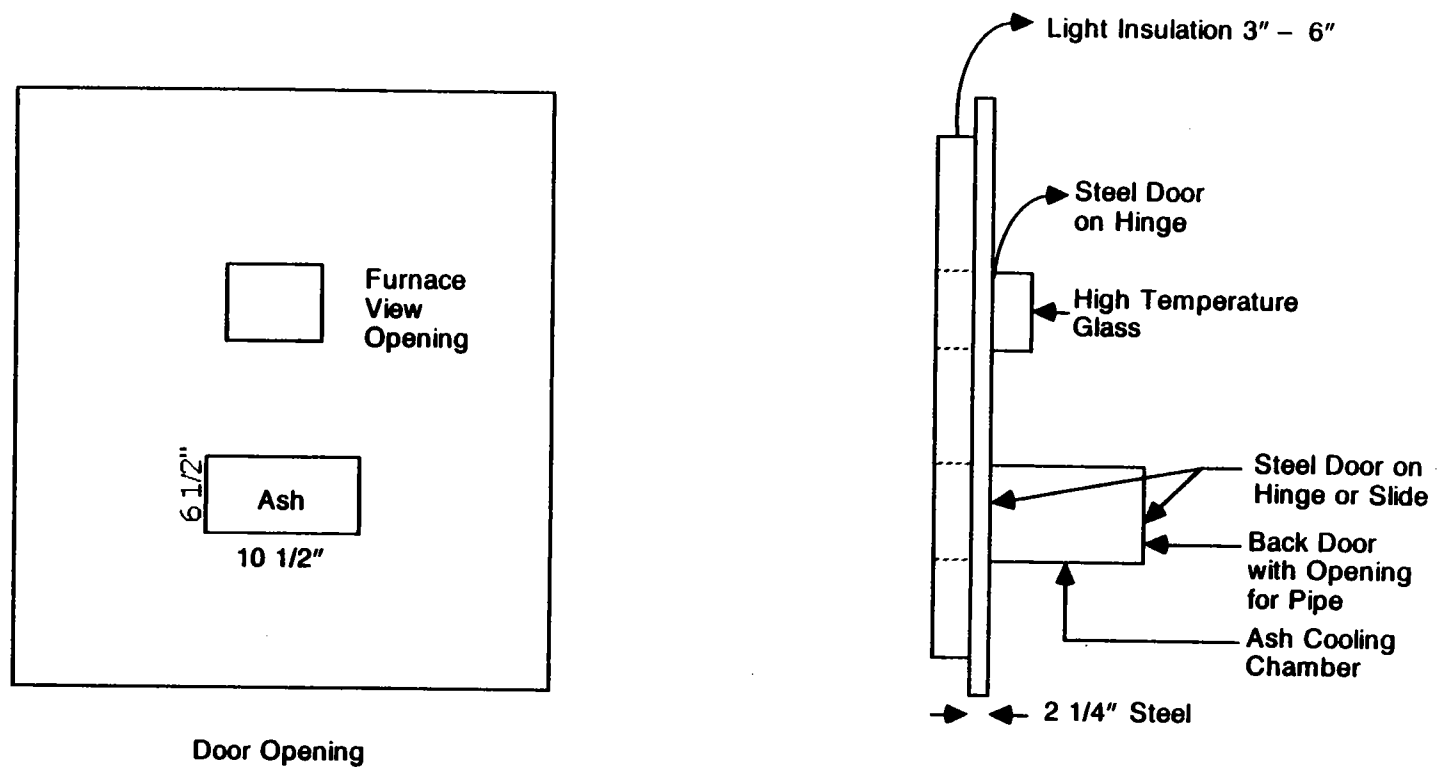
Figure 4.2

QUEBEC INCINERATOR

Main Airlock System and Incinerator Back Door

43138

4.3.2   Boiler/Economizer Ash

A specially designed breach was installed on the boiler/economizer and precipitator conveyor drop chute to diverge the ash from the incinerator quench tank to a 45-gallon drum. Only boiler/economizer ash was collected at this location since all of the precipitator ash was collected prior to reaching the drop chute diversion point.

4.3.3   Precipitator Ash

An enclosed bulk flow conveyer is used to transport the ash discharged from the two hoppers under the precipitator to the above-mentioned drop chute.

On the underside of the bulk flow conveyer, a trap was installed to drop out all the precipitator ash into a custom-made container. This prevented the precipitator fly ash from reaching the drop chute and permitted collection of all the ash.

4.4   FLUE GAS SAMPLING PORTS

4.4.1   Continuous Gas

Gas sampling probes were installed in parallel with thermocouples in each of four 10 cm ports located at the induced draft (ID) fan outlet as shown in Figure 4.3. Also, a 10 cm port was also installed 50 cm higher than the sampling probe for theallation of particulate concentration sampling equipment.

4.4.2   Manual Sampling

For the sampling of organics, particulates, acid gases, particle size distribution, metals, and mercury, eight new sampling ports were installed in the exhaust duct, as shown in Figure 4.3. A new elevated platform with appropriate safety railings and access to all ports was installed as well.

Two new small ports (50 mm) were installed up-stream of the sampling location for the installation of the continuous flue gas flow and temperature measurement equipment.

MANUAL SAMPLING
● NOUVELLES BUSES 150∅
● NEW 150∅ PORTS

FLOW MEASUREMENT
NEW PORTS 50∅

1700x1700

● EXISTING PORTS
● BUSES EXISTANTES

90

180

● EXPANSION JOINT
● JOINT DE DILATATION

● NEW 100∅ PORTS
● NOUVELLES BUSES 100∅

CONTINUOUS GAS

1700x1700

1700x1700

1000

3000

3000

4300

3700

I.D.   FAN
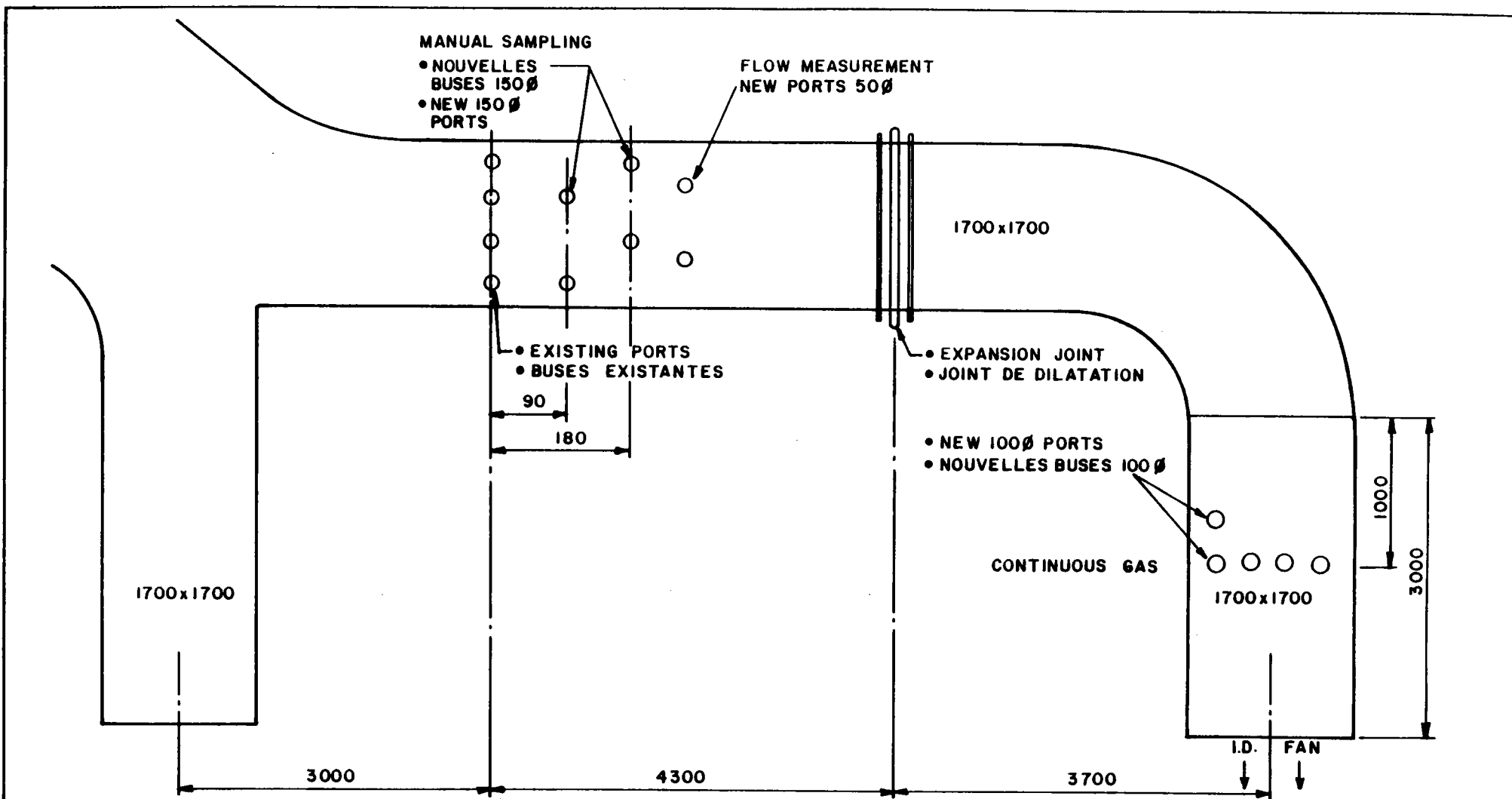
FIGURE 4.3

QUEBEC INCINERATOR

PORTS INSTALLATION ON THE EXHAUST DUCT

BUSES D'ECHANTILLONNAGE SUR LE CARNEAU INTERMEDIAIRE

4.5   COMPUTER PROCESS CONTROL COMPUTER DATA

As discussed in Section 2.9, the process control computer system installed was a Bailey Network 90 consisting of two colour screens, two control boards, and two printers. The Bailey datalogging system stored all the process information on diskette. Information from the system could only be reviewed using the Network 90 system and could not be transferred to a personal computer. To link the NITEP data acquisition system with the Bailey Network 90 system, a personal computer interface (RS232) was installed on the process computer which permitted the NITEP data acquisition system to read the process data on a real-time basis and store for future analysis.

4.6   ON-SITE FACILITIES

To facilitate the NITEP field crew, two offices were provided by the plant administrators. One office was used as the computer control room, housing the computers of the data acquisition system, and the second office was used as the site and meeting office.

In addition to the above, one truck and three trailers were brought on site. The truck housed the portable laboratory for organic sample recovery, while the trailers were used for the following:

●   storage of samples and equipment;
●   Environment Canada's site office; and
●   accommodations for inorganic sample recovery.

4.7   POWER SUPPLY

To provide stable power to the continuous gas monitoring, stack sampling equipment, and site trailers, a 25 KVA power transformer was installed.

4.8   COMMUNICATION

A hard wire telephone and paging system was installed at each critical sampling location to assist in test coordination efforts and to enable communication between stations.

Telephones were also installed in the communications office to permit the transfer of test information to external computers via modem. Interested parties in both Ottawa and California were able to observe both process and continuous gas data on a real-time basis.

5.0 MEASUREMENT METHODOLOGY

Methods of documenting the basic combustion parameters of the unit, as well as the basic methodologies of sampling fuel(s) and ash, and monitoring heat recovery are well documented in the Association of Mechanical Engineers (ASME) Power Test Codes and the Association for Testing of Materials (ASTM) Standards. However, the level of effort involved in the interpretation of these documents and development of practical testing and sampling methodologies is significant. The experience of the key members of the study team, their accumulated knowledge of the site and processes through the Quebec Incinerator Design Modification Program and test phases and emission sampling of the unit, have been of specific assistance in resolving the problems and difficulties involved in converting well-developed methodologies into rational test programs and accurate results.

The equipment and procedural details of basic particulate stack sampling are very extensively documented (ref. EPS 1-AP-74-1; USEPA Methods 1, 3 and 5, CSA Z228, 1 Joy Bulletin 50). However, the application of this basic methodology and equipment to field testing for the quantification (or even identification) of trace organic species is in the developmental stages. Although a number of groups, including Environment Canada, the US EPA and the Ontario Ministry of the Environment, have supported and promoted research in this area, currently ASME and others are attempting to resolve several technical issues and to develop a 'consensus standard'. Not the least of these issues is the definition of special analytical requirements after field samples are collected. While the technical merits of methods, equipment and procedures are still being argued, quality control samples analyzed by preselected methods in many instances fail to show consistency. Although this is not unexpected when looking for picogram levels of complex organics, it has frustrated the comparison of test results and restricted the extent of analyzing the possible correlations between test results and process parameters.

5.1 OVERVIEW

In order to draw useful conclusions and recommendations from the results, it is necessary to obtain reliable data. It is important to develop sound methodologies for the sampling program and to have them clearly recorded for future reference and/or review.

All instrumentation and sampling methods employed during the test program used recognized standards where available. Any deviation from these recognized standards has been documented and accompanied by the rationale for the change. Volume III of this report series details the sampling and analytical protocols employed; Table 5.1 presents a summary of measurement methods for the Characterization and Performance Tests.

Previous methodologies, developed for the NITEP PEI and Air Pollution Control Technology studies and reported in The National Incinerator Testing and Evaluation Program reports, were adopted where possible. The methods and protocols selected were reviewed in terms of their application to the

Quebec mass incinerator and adapted where necessary to the different site conditions, as described in the following sections.

TABLE 5.1
SUMMARY OF MEASUREMENTS

Sampling Location	Monitored/ Sampled Parameter	CT Runs	PT Runs	Protocol Section
Refuse	Rate and Sampling	X	X	5.2
Incinerator	Temperature	X	X	5.3
	Observations	X	X	5.6
Primary and Secondary Air	Temperature, Flow, Relative Humidity	X	X	5.5
Incinerator Ash	Rate and Sampling		X	5.4
Boiler Ash	Rate and Sampling	X	X	5.4
Precipitator Ash	Rate and Sampling	X	X	5.4
Exhaust Gas	Combustion and Trace Gases;	X	X	5.5
	Moisture		X	5.5
	Metals/Particulate		X	5.5
	Particle Size /HCl	X^2	X	5.5
	Mercury		X	5.5
	Organics		X	5.5
Control and Instrumentation	Record from Plant Gauges	X	X	5.6

Note a: CT-14 and CT-15 only

One specific clock was designated as the "official test clock" to which all other clocks were synchronized, and from which all official start, stop, and end times were taken.

Specific methodologies have been outlined for the following samples:

- refuse;

- ash - incinerator grate, boiler/economizer, precipitator, and quench tank;

- flue gas - analysis for stratification, flow, temperature, pressure, moisture, trace organics, particulates/metals, particle size distribution, acid gas, and mercury; and

- leaching test samples.

Sampling duration was not less than 4 hours of actual sampling time per test run. The start and end times for each traverse were synchronized for all of the manual sampling trains, i.e. organics, particulates/ metals, particle sizing/acid gas, and mercury.

Continuous monitoring (and data storage) was carried out for:

- process parameters such as steam rate;
- temperature - radiation chamber, boiler inlet, precipitator outlet, and combustion air; and
- continuous gas.

This chapter also describes the data acquisition system and data processing, and the equipment calibration procedures.

5.2   REFUSE MEASUREMENT

The material charged during the test period was representative of the material burned during normal operation and for which the unit was designed. Every effort was made to stay as consistent as possible with the feed material from test to test. All incoming waste was adequately mixed in the refuse pit before being charged to the test unit, with precautions taken to prevent density segregation. Any material normally considered inappropriate for processing was removed.

5.2.1   Refuse Charging Rate

The total weight of refuse charged during the test period was determined on an hourly rate basis. The scales used for weighing had a range of scale error within 0.25 percent for the range of loads weighed. Scales were zeroed using the crane bucket before and after each test day. The crane bucket weight was also measured prior to and after each test, to verify that the scale was still calibrated.

Each crane bucket load was weighed immediately before charging the load into the feed hopper. The time, weight and charge description were recorded. The weight was also logged by the data acquisition system for the calculation of the real-time efficiency display.

The average load weight was approximately 1200 kg, with a frequency of three consecutive loads every 15 minutes.

The refuse charging rate was measured during both the Characterization and Performance Test runs.

5.2.2   Refuse Sampling

Refuse sampling was carried out only during the Performance Tests. Throughout each Performance Test day, 4-5 trucks were randomly chosen to discharge a portion of their load onto a steamed, pre-cleaned floor. Only trucks that carried municipal refuse were chosen. Trucks carrying industrial refuse, restaurant or hospital wastes were not sampled because their contents would not be representative of the incinerator's total intake.

All of the collected garbage was spread out and sorted to remove large pieces of metal and undesirable material such as appliances and large glass bottles which would not pass through the shredder. All removed items were then weighed and disposed of after each Performance Test. A mini-loader was used to place the garbage into a low rpm, 40 hp shredder which was able to shred items such as tin cans, wood and glass. The shredded material was then coned and representative samples obtained by randomly inserting a shovel into the bottom of the refuse pile, drawing the shovel upwards to remove the sample.

The collected refuse samples were placed in heavy gauge, vapour-impervious plastic bags. Each bag was then tightly sealed to prevent evaporation, loss of moisture and loss of organic volatiles. The bags were then placed in 5-gallon plastic pails for further protection.

Weights of the empty pail, liner lid, and empty plastic bags had been measured and recorded. The container when filled with the sample, was then weighed and the weight recorded. The total weight was marked on each container along with a unique identification number code; both were then recorded on a log sheet. The difference in weight represented the weight of the packaged sample.

On standard testing days, four 5-gallon samples were taken. For each mode of operation an extra refuse sample was taken for leachate analysis. All samples were then taken to the on-site trailer for cool storage until distribution for analysis.

At the beginning of each test, all equipment and floors were steam-cleaned.

To assess the variability in composition of the refuse feed to the incinerator, triplicate sampling was carried out during PT-14. The total sample period was divided into three equal time intervals; shredded refuse from each interval was put into separate piles. One sample was taken from each pile and analyzed, in triplicate, for U/P/HHV, organics and metals.

5.2.3   Refuse Sample Preparation

The distribution of refuse sample pails for each Performance Test was as follows:

Pail #1 :   air-dried, shredded, milled and sent for organic, metals, ultimate (U), proximate (P) and High Heating Value (HHV) analyses;

Pail #2 :   oven-dried for moisture content;

Pail #3 :;   air-dried for moisture content;

Pail #4 :   air-dried for moisture content; and

Pail #5 :   air-dried, shredded and sent for leachate analysis.

5.2.4   Plastic Classification

A plastic refuse sorting program and a plastic classification program were carried out during the Performance Tests. Eight (8) complete tests were conducted over the testing period.

The three-phase plastic sorting procedure was implemented as follows:

● Plastic extraction from the refuse;

● Plastic separation according to the type (such as foam, film, plastic molds); and

● Plastic separation according to the resin classification (such as PET, PVC, polystyrene).

The first phase involved the extraction of plastic materials from the refuse. As stated in Section 5.2.2, refuse samples were taken from the contents of 4-5 trucks for each Performance Test. These same trucks were selected to discharge part of their load for plastic sorting. For each designated refuse test run, between 500 and 1000 kg of refuse was set aside to form a representative feed sample. The sample was delivered to the truck unloading zone and discharged onto the floor, in an area separate from other refuse samples destined for laboratory analysis.

Plastic materials were removed from the refuse and hand-sorted based on type, then deposited into pre-weighed containers. The plastics classifications were:

● Films;

● Molded products;

● Foam;

● Composite products; and

● Others.

Upon completion of the sorting, each container was weighed in order to determine the net weight distribution of each classification.

Subsequent to the initial sorting, the same plastic materials were re-sorted according to resin classification. The identified resin classifications were:

- Polyethylene (PE) and polypropylene (PP);
- Polystyrene;
- Polyvinyl chloride (PVC);
- Polyethylene terephthalate; and
- Others.

Most plastic materials were easily sorted by their visual properties. In the few cases where this was not possible, certain mechanical properties such as density, melting point, and burning characteristics, were determined in order to designate an appropriate type or resin classification. Again the net weight distribution was determined for each category.

5.3   TEMPERATURE MONITORING

Temperatures were monitored at the following locations:

- the furnace radiation chambers;
- the boiler inlet;
- the precipitator outlet;
- the air supply duct (combustion air); and
- ambient air.

Thermocouples were installed at these locations and connected to the data acquisition system to automatically record and display these temperatures, updating every thirty seconds.

5.3.1   Radiation Chamber

A thermocouple grid was installed at the level of the existing side observation doors in the radiation chamber, as shown in Figure 4.1, to measure the radiation chamber temperature profile. Thirty-two (32) type "K" thermocouples were attached to four (4) steam-cooled probes at 45.7 cm intervals in a grid network. All thermocouples were interfaced with the data acquisition system.

Two probes were installed through the 15.2 cm ports in the side observation doors across the radiation chamber. The front probe was supported by the door opening on the west wall, and a welded support on the east waterwall. The rear probe was supported on the east and west sides by the openings in the observation doors.

Throughout the Characterization Testing, the radiation chamber temperature probes experienced slow degradation of the probe manifolds and thermocouple tips due to the high incinerator temperatures and corrosion, and hence were not operable at the conclusion of the Characterization Testing. Because of the unavoidable slag buildup on the probes from the flyash, causing non representative readings, and the high cost associated with replacing the thermocouples, it was decided that the thermocouples would not be replaced for the Performance Testing.

5.3.2   Boiler Inlet

Twenty (20) thermocouples (Type K) were attached to the screen tubes to measure a profile of the boiler inlet flue gas temperature. The thermocouples were installed at intervals such that they provided equal areas for each of the 20 thermocouples. All thermocouples were interfaced with the data acquisition system.

Due to the high corrosion which occurred during the Characterization Test, the thermocouples at the boiler inlet were replaced with the same type for the Performance Test.

5.3.3   Precipitator Outlet

Six (6) type "K" thermocouples were attached to the continuous gas probes at the induced draft (ID) fan outlet to measure exhaust gas temperature.

In addition, two (2) thermocouples were installed on the horizontal section of the exhaust duct in parallel with the two pitots.

5.3.4   Combustion Air

Two thermocouples were installed in the duct of the primary and secondary air supply after the air supply fans. They measured:

- overfire (secondary) air temperature, and
- underfire (primary) air temperature.

Two thermocouples were installed at the refuse feed chute. They measured:

- wet and dry bulb temperatures, and
- dry air temperature.

5.4   ASH SAMPLING

The process efficiency, and the quality and quantity of the unburnables, i.e., ash, had to be established. To achieve this, the following samples were taken:

● incinerator grate ash,
● boiler/economizer ash,
● precipitator ash, and
● quench tank ash.

The weigh scale for ash rate determination employed during the Performance testing had a range of scale error within 0.25 percent for the range of loads weighed. The scale was calibrated prior to and after each test in accordance with the ASME performance test code PTC 19.10.

5.4.1   Incinerator Grate Ash

As described in Section 4.3, incinerator ash samples were taken from a specially designed and built port located directly across from the finishing grate. (From here, incinerator ash would drop into the quench tank below.) A stainless steel (SS) shovel was inserted into the furnace at different locations at the end of the finishing grate. Ash samples were collected every 15 minutes in order to obtain representative samples. All of the collected ash was immediately placed into a SS container with dry ice, covered, allowed to cool and then transferred to a tared 45-gallon holding drum. Dry ice was used not only to cool the sample quickly, but also to prevent further burning of the sample, such that an analysis of the combustibles still present in the sample could still be carried out and the ash quality determined.

Once the sampling was complete, the weight of the contents of the drum was determined, and the contents unloaded onto the pre-cleaned floor at the sampling location. The combined sample was then coned and quartered. One of the coned quarters was placed into a single 5-gallon plastic-lined pail which was then hand-delivered to the sample recovery trailer.

Ash sampling on the incinerator grate was attempted for a few Characterization Test runs to assess the feasibility of this sampling procedure and to determine if meaningful results could be obtained on analysis of these samples. Since these attempts proved successful, incinerator grate ash sampling was realized for all Performance Test runs.

5.4.2 Boiler/Economizer Ash

Thirty minutes after the start of each run, the boiler/economizer ash was diverted to a tared 45-gallon drum. Each epoxy-lined drum was pre-weighed and steam-cleaned. At the end of the run, the drums were weighed and the ash weight calculated by subtraction.

At the completion of the run the ash was thoroughly mixed, coned and quartered on a section of the pre-cleaned concrete floor, and placed in four pre-proofed glass containers fitted with moisture-tight, sealer-type lids. When leachate samples were requested, a 5-gallon pail was also filled.

Boiler/economizer ash sampling was carried out for two (2) Characterization Test runs to determine the feasibility of the sampling procedure and then carried out for all of the Performance Test runs.

5.4.3 Precipitator Ash

Precipitator ash was collected from the plant ash conveyor system by placing a specially built, epoxy-lined container underneath the chain conveyor and allowing ash to fall by gravity into the container. Prior to the start of sampling, a plate under the conveyor was removed and a container installed. When the container became full (every 10 to 20 minutes, depending upon fly ash quality) the contents were emptied into a pre-weighed, pre-cleaned 45-gallon drum and the container replaced. (Each epoxy-lined container was steam-cleaned prior to installation.) Once full, the sample drum was tared. Two tube-like samples or "carrots" were inserted into the drum and a sample "cork" extracted from each drum; the remaining ash was discarded.

At the completion of the run the sample cork was thoroughly mixed, coned and quartered, and placed in four pre-proofed glass containers fitted with moisture-tight, sealer-type lids.

Again, the ash sampling procedures were rehearsed during a number of Characterization Test runs and executed for all Performance Test runs.

5.4.4 Quench Tank Ash

To calculate the amount of incinerator ash produced each day, the quantity of quench tank ash and its moisture content were required. To obtain the ash quantity, the ash pit was emptied prior to the beginning of each run. Upon completion of the run, the ash pit was again emptied, its contents loaded onto a truck and weighed. The weight of the empty truck was obtained from the plant scales and subtracted from the total weight to give the wet ash weight. A representative sample of the quench tank ash was taken from the truck and scooped into a pre-cleaned glass container (Mason jar) and

sealed once full. The ash sample was then hand-delivered to the sample recovery trailer where it was routed for moisture content and combustibles analysis. One jar of quench tank ash was collected per Performance Test run. For interest's sake, on the last two runs, PT-14 and PT-15, a 5-gallon pail of ash was collected each day to assess the homogeneity of the quench tank ash.

For both the organic and leaching analyses samples, one jar of quench tank liquid and one jar of solids were required for each test run. The solids sample was taken directly off the quench tank ash conveyor during the night shift at approximately midnight, after the unit was stabilized. Quench tank ash was collected by scooping the wet ash into a pre-cleaned glass jar and sealing the jar once full. The liquid sample was taken from the quench tank, as well during the night shift at approximately midnight. This sample was collected by allowing the top layer of water in the tank to flow into a pre-cleaned glass jar. Once full, the jar was sealed, wiped dry, and labelled. Both samples were then hand-delivered to the sample recovery trailer.

5.5   FLUE GAS SAMPLING

The flue gas was sampled for a number of reasons. The flue gas is, in effect, a product of the incinerator process and as such must be analyzed to assist in the determination of the process efficiency and emissions. Not only do emissions of environmental contaminants dictate the acceptability of incineration as a viable procedure for waste disposal, but from a process point of view, flue gas monitoring is essential since changes in the process operation are reflected in the flue gas composition. Comparison between concentration variances from test to test helps to identify the optimal process parameters for the incinerator.

The flue gas was sampled for the following:

- stratification across the duct;
- flow, temperature, pressure, and moisture;
- continuous gases (CO_2, CO, Total Hydrocarbon, O_2, SO_2, NO_x);
- metals/particulates;
- trace organics;
- particle size distribution/acid gases; and
- mercury.

The exhaust gas sampling methodology and analytical procedures are summarized in Table 5.2. Section 4.0 describes in greater detail the port locations on the exhaust duct from which the flue gas was sampled. As illustrated in Figure 4.1, (see Section 4.2.1), each of the ports were located at different distances from the forced draft (FD) fan in the duct. A sampling "traverse" consisted of samples taken at various points across the duct using the same sampling port. Each test run consisted of four traverses, such that sampling across the duct was carried out at all four port locations.

TABLE 5.2
SUMMARY OF EXHAUST GAS EMISSION SAMPLING METHODOLOGY

Sampling Equipment	Protocol	Monitored/Sampling Parameter
Modified Method E	A.S.M.E. Draft 4 Oct. 84	Dioxins, Furans, PCB's, Chlorophenols, Chlorobenzenes, PAH's
Probe, Filter, Heated Line	CSA Z223.2-M Draft	Combustion Gases, Trace Gases
Modified Method E	E.C. EPS 1-AP-74-1,	Mercury
Modified Method E	E.C. EPS 1-AP-74-1, EPS 1-AP-76-1	Trace Metals, Major Metals
Method E	E.C. EPS 1-AP-74-1	Particulate, Acid Gases
Cascade Impactor	Single Point, In-Stack	Particle Size
Opacity Monitor	Existing	Opacity
Thermocouple	A.S.M.E. PTC 19.3	Temperature

The traversing of all trains was timed to coincide with each other and the sampling duration of each Performance Test was not less than 4 hours of actual sampling time. All official start and end times for each traverse were taken.

5.5.1   Stratification

Stratification tests were carried out during Characterization Tests, CT-14 and CT-15, to assess the adequacy of the flue gas sampling location. Four sampling trains were operated simultaneously from four ports across the horizontal section of the duct to sample the particulate loading and to measure the gas velocity.

Sampling proceeded according to the basic principles described in EPS 1-AP-74-1 with the installation of a 47 mm in-stack filter affixed to the tip of the probe. The decision to use the in-stack filter was based on its fast turn-around time for field equipment usage. Because it is a small and low weight filter, sampling and cleaning times were minimized.

5.5.2   Flow, Temperature, Pressure, and Moisture

Exhaust gas flowrates were measured on a continuous basis by two pre-calibrated S-type pitots in the exhaust duct. The pitots were attached to two transducers and voltage signals were recorded by the data acquisition system.

Temperature and flowrate of the exhaust gas were also measured by the four stack samplers; two thermocouples were attached to the pitots and six thermocouples attached to the continuous gas probes. All of the thermocouple readings were recorded by the data acquisition system.

Duct pressure was measured at the beginning of each day using an incline manometer.

Moisture was measured by the manual stack sampling equipment.

Measurements of flow rate and temperature of the exhaust gas were carried out during both the Characterization and Performance Test phases. Pressure and moisture measurements were taken during all Performance Test runs but only during two Characterization Test runs, CT-14 and CT-15, ie. when stratification tests were carried out.

5.5.3   Continuous Emission Monitoring

Continuous stack gas monitoring was carried out on the exit side of the electrostatic precipitator. This following section describes the sampling systems, analyzers, and calibration gases/procedures used.

Sampling Systems

A multi-point sample extraction system was designed and constructed based upon the sampling point criteria in ASTM PT-10.

The extraction system consisted of two probes, each of which sampled the gas flow at three locations. The points were located at the geometric centres of six equal area rectangles within the stack, as indicated in Figure 5.1.

The diversity of analyzers used during the program required three independent conditioning systems. The following list indicates the gases analyzed in each system:

Sampling System 1   - HCl
Sampling System 2   - THC(hot)
Sampling System 3   - Multi-component Analyses (SO_2, NO_x, CO, CO_2, THC(cold) and O_2)

Heated Transfer
Boxes

Probes

◉ Sample Extraction Point
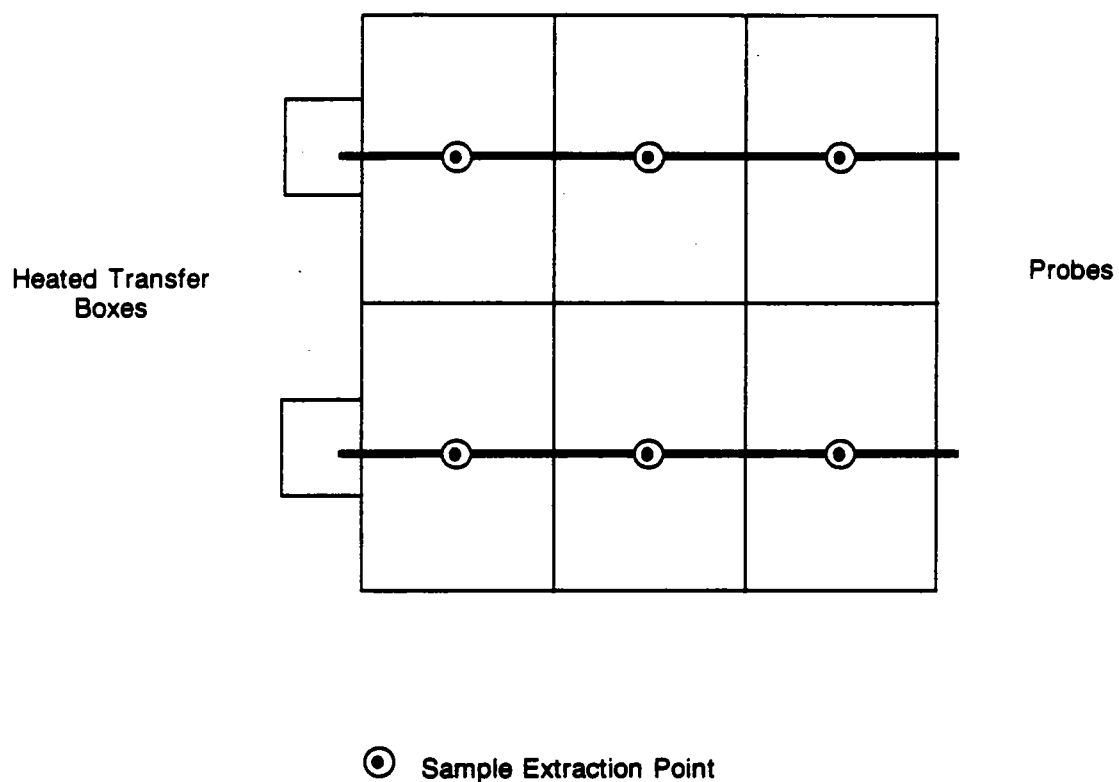
Figure 5.1
QUEBEC INCINERATOR
Location of Sample Extraction Points

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Details on each are presented in the following three sections.

HCl Sampling System

The HCl gas sample was extracted from six locations in the stack via short lengths of 1/4-inch diameter stainless steel tubing welded into holes drilled in the two probes, which were fabricated from 1/2-inch schedule 40 stainless steel pipe. Each probe extended from a sample transfer box affixed to one side of the duct, through the gas flow, and out the opposite side of the duct through a leak-free fitting. The probes were aligned in the duct such that the ends of the tubes faced downstream in the gas flow, minimizing the quantity of particulate material drawn into the sampling system. Glass wool plugs located within each probe removed particulate matter from the sample. See Figure 5.2.

The flows from the two probes were blended by joining equal lengths of Teflon tubing at a tee. A secondary glass wool filter in the transfer box removed additional particulate matter and any products of corrosion. This was followed by a permeation drier which removed water vapour from the gas sample. The HCl sample was transported to the remote analyzer through an unheated Teflon line 50-feet in length and 1/4-inch in diameter. The HCl analyzer pump was used to pull the gas sample through the system. A schematic of this sampling system is presented in Figure 5.2.

THC(hot) Sampling System

A flue gas sample was extracted from the six designated locations using probes constructed of 3/8-inch stainless steel tubing. The ends of the tubes faced downstream in the gas flow thus minimizing the quantity of particulate matter drawn into the probes with the gas sample. The flows were blended inside the heated transfer boxes then a heated filter removed particulate matter. No further conditioning was necessary as the sample was analyzed on a wet basis.

The sample was transported to the remotely located analyzer through an electrically-heated Teflon line, 1/4-inch in diameter and 50 feet in length, maintained at 121°C. A heated-head pump, located at the end of the heated sample line pulled the sample through the system. Details on this sampling system can be found in Figure 5.3.

Multi-Component Sampling System

This gas sample was extracted from six locations in the stack using probes constructed of 1/4-inch stainless steel tubing. Particulate matter was removed by in-stack sintered stainless steel filters (1.5 inches in diameter, 9 inches long) located at the tip of each probe. The gas flows were blended inside the heated transfer boxes. A 50-foot long, 1/4-inch diameter Teflon sample line, electrically-heated to 121°C, carried the gas sample to the conditioner.

A heated filter at the conditioner removed residual particulate matter. A heated-head pump, maintained at 177°C was located downstream of the filter. A permeation drier or Teflon heat exchanger removed water vapour from the sample after which the cool, dry sample was distributed to the various analyzers

Sample Extraction

Heated Transfer Boxes

Extraction Points

Probes

Gas Flow

Details on
Extraction Point

0.25″ SS Tubing

0.5″ Sch. 40
SS Pipe

Glass Wool Filter

Sample Conditioning

Internal Filter

Heated Transfer Box

Gas sample
from probes

Permeation Drier

Teflon Line
to Analyzer

Calibration Gas
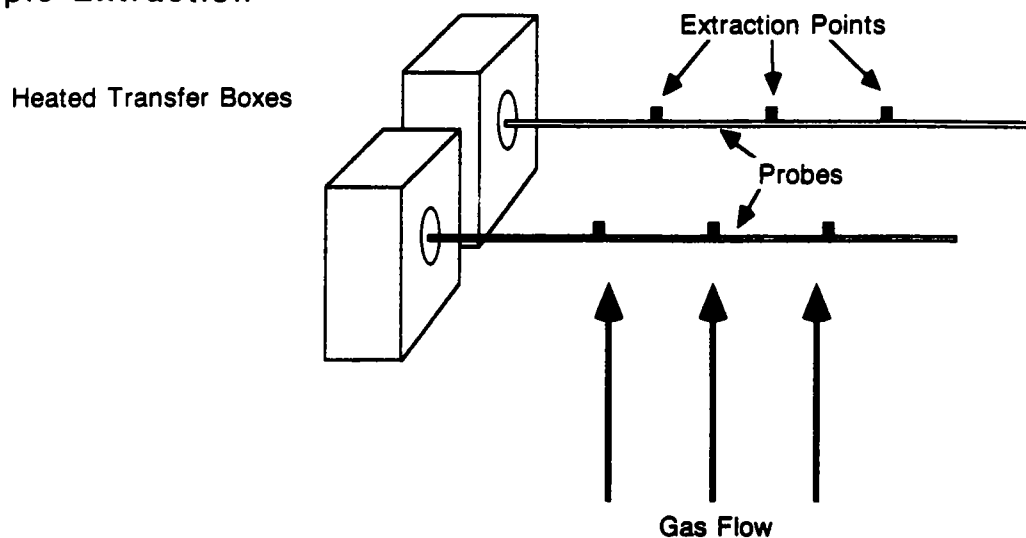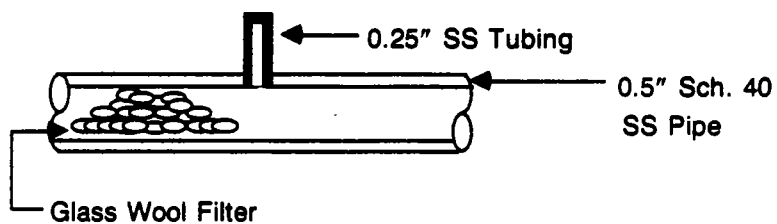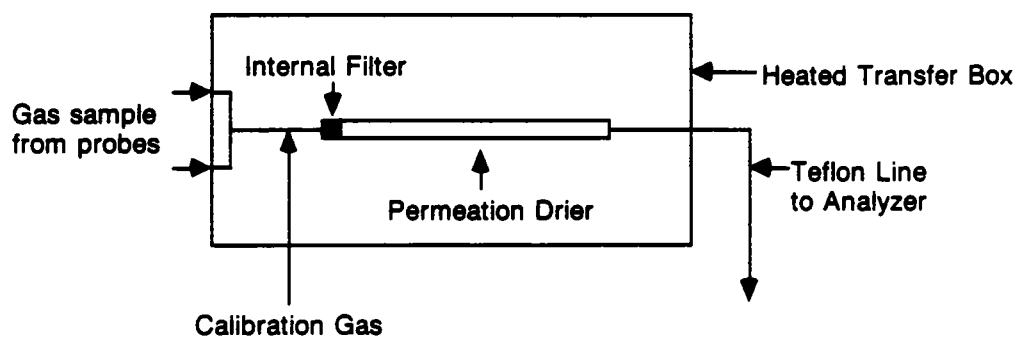
Figure 5.2
QUEBEC INCINERATOR
HCl Sampling System

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Sample Extraction

Heated Transfer Boxes

Extraction Points

Probes

Gas Flow

Details on
Extraction Point

3/8″ SS Tube

Sample Conditioning

Heated Transfer Box

Gas sample
from probes

Filter

Heated sample
line to analyzer

Calibration Gas
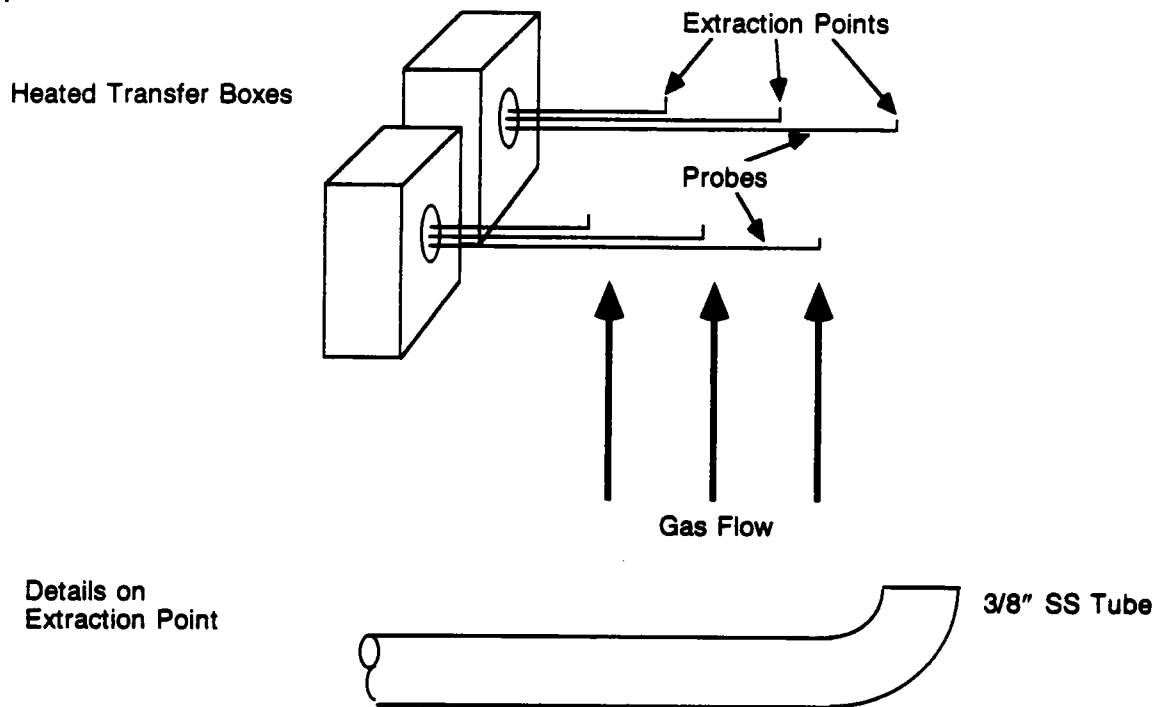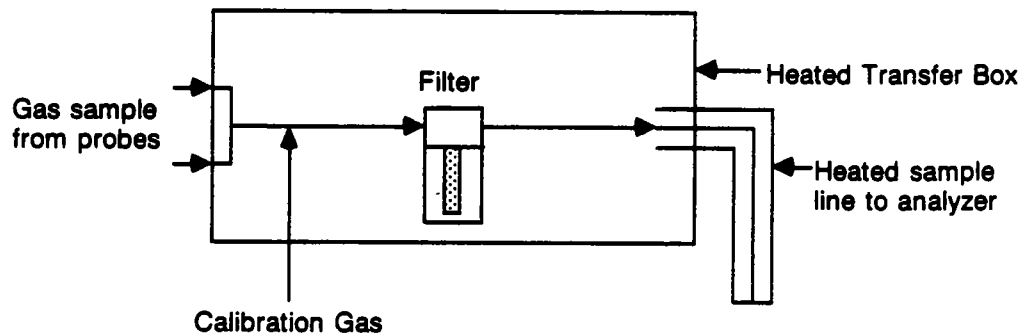
Figure 5.3
QUEBEC INCINERATOR
THC (hot) Sampling System

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according to their individual requirements. A schematic of this sampling system is given in Figure 5.4. For comparison purposes, a summary outlining the main components in each sampling system is provided in Table 5.3.

Analyzers

A total of eight gaseous and one particulate analyzer were operated during the study. Standby analyzers were available on site for all units, HCl and particulate units excepted. Table 5.4 presents basic information on these analyzers.

Calibration Procedures

The accuracy of data generated by continuous monitors is a function of the accuracy of the concentration of calibration gases used and of the system calibration procedures. To ensure maximum accuracy of the data during the program, emphasis was placed upon verification of the concentrations of the gas standards used and provision of satisfactory system calibration procedures.

The three sampling systems were calibrated on-site before and after each test by injecting verified calibration gases at designated locations in each sampling system. Additional checks were made during tests by injecting calibration gases directly to selected instruments.

All calibrations were controlled from the continuous monitoring shelter which housed the calibration control equipment. Teflon lines carried the calibration gases from the calibration control module to the various injection locations. Sufficient span or zero gas was supplied to satisfy the total flow requirements of the system with a slight excess gas flow back through the probe into the duct. The calibration gas injection points are indicated on the diagrams of the three sample conditioning systems HCl, THC (hot) and the multi-component stream respectively (see Figures 5.2, 5.3 and 5.4).

The calibration of each system using the appropriate gas mixtures was carried out immediately before each test and immediately after the conclusion of each test. These calibration results were annotated on the chart recorder traces and submitted for QA review on a daily basis.

Periodic checking of the zero and span drifts of the THC(cold) analyzer by direct injection of gases to the analyzer was found to be necessary because of the low concentrations being measured.

5.5.4   Metals/Particulates

During the Performance Tests, particulates and heavy metals were determined using the equipment and procedures described in EPS 1-AP-74-1. The modified Method E train with five Greenburg-Smith impingers connected in series, contained the following solutions:

Sample Extraction

Heated Transfer Boxes

Extraction Points

Probes

Gas Flow
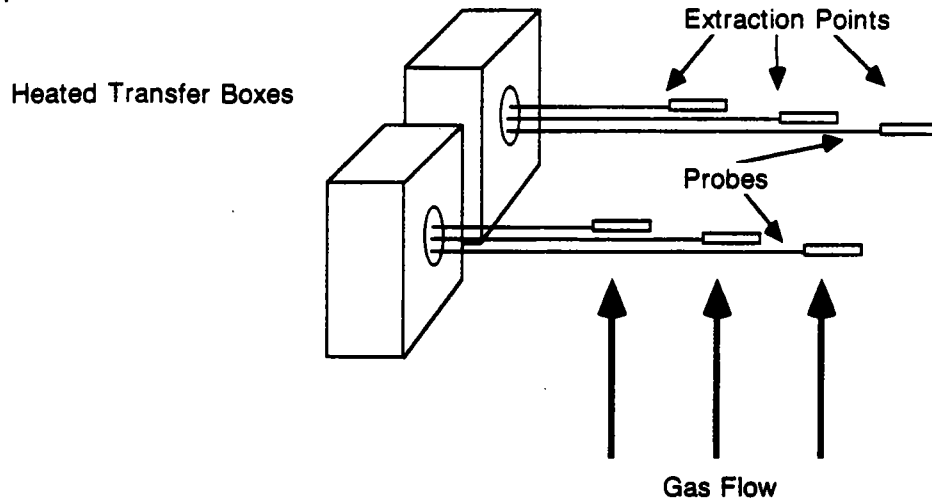
Details on Extraction Point
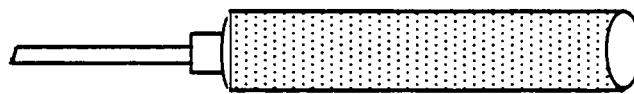
Sintered SS Filter

Sample Conditioning

Heated Transfer Box

Gas sample from probes

Heated sample line

(C)   (A)

(C)

(A)   Heated filter box

Heated – head pump

Filter

Calibration Gas (C)

Teflon Heat Exchanger

Permeation Drier

Water Removal Pot

(C)

To   Analyzers
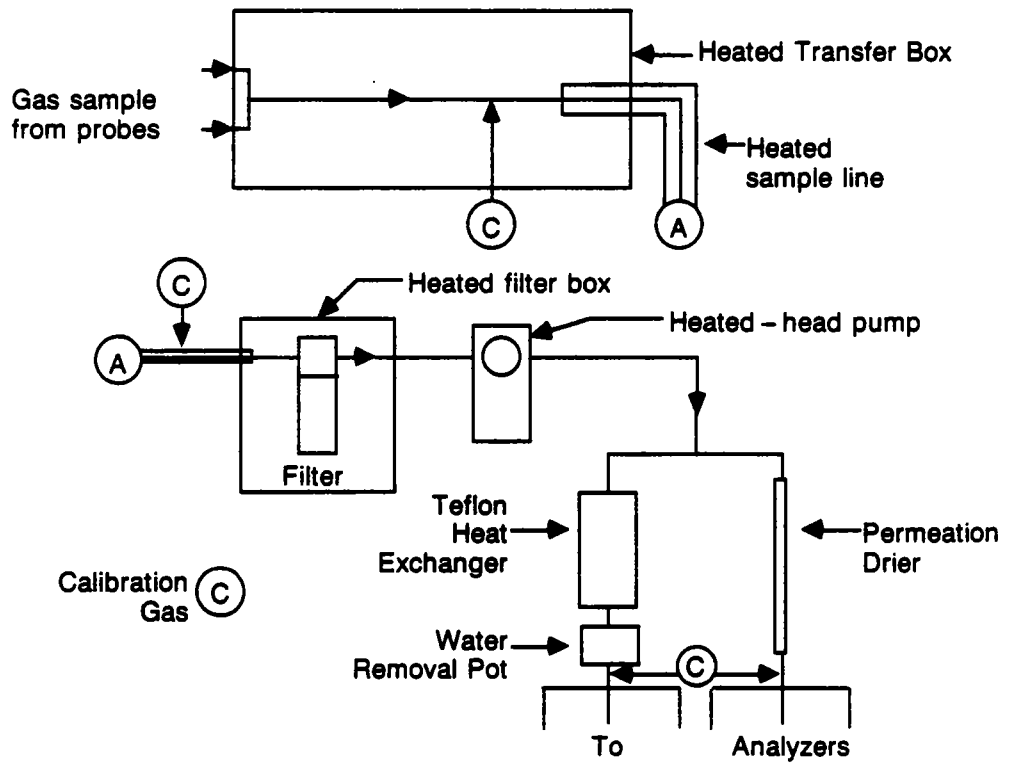
Figure 5.4
QUEBEC INCINERATOR
Multi – Component Sampling System

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TABLE 5.3 - DESCRIPTION OF SAMPLING SYSTEMS

System No.	Gases	Measurement Basis	Particulate Removal Procedure	Water Vapour Removal Procedure	Sample Line	Sample Pump
1	HCl	Dry	2 Internal Glass-Wool Filters	Permeation Drier	50 feet long; 0.25 inch OD Unheated Teflon	Internal Analyzer Pump
2	THC(h)	Wet	Heated Filter	n/a	50 feet long; 0.25 inch OD Heated Teflon	Internal Analzer Pump and Heated Head Pump
3	SO_2 O_2 CO_2	Dry	Sintered S.S. Filters and Heated Filter	Permeation Drier	50 feet long; 0.25 inch OD Heated Teflon	Heated Head
	NO THC(c) CO			Teflon Heat Exchanger		

TABLE 5.4 - ANALYZER INFORMATION

Component	Status (Main, std/by)	Manufacturer	Model	Basis of Measurement	Principle of Operation*	Range #
SO_2	M	WRD	721	Dry	NDUV	0-250
NO_x	M	TECO	10AR	Dry	Chemi	0-250
CO	M	Bendix	8501	Dry	NDIR	0-500
HCl	M	TECO	15	Dry	GFC	0-1000
THC(h)	M	Horiba	34A	Wet	FID	0-30
THC(c)	M	Beckman	400	Dry	FID	0-20
O_2	M	Beckman	755	Dry	Para	0-25%
CO_2	M	Beckman	765	Dry	NDIR	0-20%
Partic.	M	ESC	P5A	Wet	Backscatter	n/a

Units are in ppm unless otherwise indicated
* **Principles of Operation**

NDUV - Nondispersive ultraviolet   FID - Flame ionization
Chemi - Chemiluminescence   Para - Paramagnetic
GCF   - Gas Filter Correlation   NDIR - Nondispersive infrared
FC   - Fuel Cell

First	- 100 ml of 5% aqua regia
Second	- 100 ml of 5% aqua regia
Third	- 100 ml of distilled water
Fourth	- empty
Fifth	- silica gel

Two types of glass fibre filters were sent out for analysis as blanks, prior to the Performance testing. It was decided, in collaboration with the Quality Control personnel, that the filters which returned the lower background trace metals concentration were suitable. Hence, Reeve Angel AH-934 glass fibre filters were used for particulate sample collection.

All equipment went through an extensive cleaning program to minimize contamination of the samples. These procedures are described in Volume III.

Between each test run the sampling train was proof-rinsed after the sample recuperation and prior to preparation for the next test run.

Sample recovery is described in 6.2.1.

5.5.5   Trace Organics

Collection of exhaust gas samples for determining the concentrations and emission rates of trace organic compounds were carried out using the equipment and procedures described in the American Society of Mechanical Engineers (ASME) method for trace chlorinated organic sampling and analysis October 1984. (Draft No. 4), as provided in Volume III.

This sampling train was used to collect samples of all the trace organic compounds listed below:

● . polychlorinated dibenzo-p-dioxins (PCDD's)

● polychlorinated dibenzofurans (PCDF's)

● chlorophenols (CP's),

● chlorobenzenes (CB's),

● polychlorinated biphenyls (PCB's), and

● polycyclic aromatic hydrocarbons (PAH's).

The organic sampling train is shown schematically in Figure 5.5. Sampling proceeded in accordance with the basic principles described in EPS 1-AP-74-1 with the inclusion of special requirements as described in the ASME Method. These requirements are listed below:

● freshly nickel-plated stainless steel nozzles were used;

● glass sampling probe liners were used;

A
PARTICULATE/METALS

AR (3) AR (3) MT (2) SG (4)

FRONT-HALF

NOZZLE STACK WALL PROBE FILTER

FLOW UP STACK

CYCLONE

B
ORGANICS

WATER COOLER CONDENSOR

XAD-2 CARTRIDGE

KNOCK-OUT TRAP

MT (2) SG (4)

ETHYLENE GLYCOL

BACK-HALF

SAMPLING TRAIN: A, B, or C

C
MERCURY

(6) (6) MT (2) SG (4)

KMn04

D
HCl

CONSOLE

DGM FLOW CONTROL VACUUM GAUGE

EXHAUST

ORIFICE METER

H_2O (1) H_2O (1) MT (2) SG (4)

LEGEND:
1 = WATER (H_2O)	3 = AQUA REGIA	5 = ETHYLENE GLYCOL ($C_2H_4(OH)_2$)
2 = EMPTY (MT)	4 = SILICA GEL (SG)	6 = POTASSIUM PERMANGANATE (KMn O_4)

Figure 5.5
QUEBEC INCINERATOR
Schematic of Sampling Trains

- only Teflon seals were used for components of the sampling train likely to be in contact with the sampled exhaust gas;

- Amberlite XAD-2 resin was used in the adsorption cartridge which precedes the impingers;

- ethylene glycol and water compounds, were used as the first impinger and second impinger solutions, respectively; and

- a thermocouple was used to ensure that the adsorption cartridge temperature did not increase above 20°C.

An extensive cleaning program was completed by the Ontario Research Foundation (ORF) for all the equipment, to minimize contamination of the sampled gas stream. This was necessary since the trace organic compounds present in the exhaust gases were at low concentrations and any contamination could have been significant. The cleaning procedures as specified by Environment Canada, the "Outline of Proofing Procedures for Sampling Trains and Sample Containers", are provided in Volume III.

After cleaning, a final rinse of all equipment was sent to Zenon Environmental Inc. for proofing analyses to determine if there were any equipment background trace organic contaminants present. The results were presented to both the Lavalin and EC QA/QC personnel for approval, ie. to decide if the results were acceptable. Similar procedures were also completed for the impinger solutions and solvent batches used in the cleaning program prior to the sampling program. All newly purchased and recycled equipment used during the sampling program underwent the same cleaning procedures.

Specially constructed probes consisting of a stainless steel sheath for the glass liner, with probe heating tape wrapped around the outside of the sheath, were used. Ferrules at the ends of the probe enabled the liner to be easily and quickly replaced.

A total of twenty sampling trains were required for the program (fifteen sample trains plus five blank trains) including spare equipment to cover extra tests and breakages. New filter frits were used for each sample or blank train. To reduce the risk of contamination, each set was identified separately and no exchange of glassware between sets was authorized.

5.5.6   Particle Sizing/Acid Gases

A five-stage multi-cyclone was used for PT-01 and PT-02. From the results of these two tests, it was evident that the particle loading was lighter than anticipated - too light for the cyclone to obtain a good weighable sample. For this reason, an Anderson Mark V cascade impactor was used during the remainder of the Performance Tests to obtain a particle size distribution for the exhaust gas particulate material. Sampling was conducted at a single point of average exhaust gas velocity. The sampler was used in conjunction with a Method E (EPS 1-AP-74-1) sampling train for hydrochloric acid (HCl).

Hydrochloric acid measurements were determined using a modified Method E train with four Greenburg-Smith impingers connected in series. The impingers contained the following solutions:

First	- 100 ml of distillate water
Second	- 100 ml of distillate water
Third	- empty
Fourth	- silica gel.

No filter was used between the impactor/heated probe and the impinger. The particle sizing and acid gas trains were combined to minimize the equipment used on the sampling platform.

Particle size/acid gas sampling was carried out simultaneously with metals/particulates, mercury and trace organic sampling. The sampling time was shortened, however, when the collection impactor became overloaded.

Section 6.2.3 presents the sample recovery.

5.5.7 Mercury

During the Performance Tests, mercury was determined using the equipment and procedures described in EPS 1-AP-74-1 and the "Recommended Method for Source Testing: Measurement of Emissions of Mercury from Incinerators" (Volume III).

Mercury was determined using a modified Method E train with four Greenburg-Smith impingers connected in series. They were:

First	- 100 ml of 4% $KMnO_4$
	- 100 ml of 20% H_2SO_4
Second	- 100 ml of 4% $KMnO_4$
	- 100 ml of 20% H_2SO_4
Third	- empty
Fourth	- silica gel.

Reeve Angel AH-934 glass fibre filters were used for particulate sample collection. These filters have acceptable background trace metal concentrations.

Sample recovery is described in Section 6.2.4.

5.5.8   Opacity

Opacity of the exhaust gas was measured by the existing opacity meter which was located on the exit side of the electrostatic precipitator, at the same height as where the continuous gas samples were extracted. The meter's location was not considered ideal in a highly turbulent region, which consequently produced high readings. These readings were apparently much too high as compared to the grain loadings and hence not considered representative of the true opacity. Thus, poor correlations were expected. On the other hand, the opacity readings were considered useful to compare between tests, indicating trends as opposed to actual expected ranges.

5.6   PROCESS PARAMETER MEASUREMENTS

All process parameters were continuously monitored by the combustion experts during each test run. In addition, the process data was recorded by the data acquisition system through the Bailey Network-90 computer system. Instantaneous readings as well as a graphical display of previous readings (called up as required on the Bailey screen for up to 24 hours prior) were utilized to evaluate system performance throughout each test run for the following parameters:

- steam flow rate,

- combustion air rates:
  - total
  - total primary and distribution
  - total secondary and distribution,

- radiation chamber temperatures,

- superheater inlet temperatures, and

- grate speed.

Flue gas composition was continuously displayed on a screen set-up from the data acquisition system, in the process control room. This data assisted the combustion experts in identifying whether the process was operating as planned or was experiencing changes or upset conditions. The most consistently utilized parameters included carbon monoxide (CO), oxygen (O_2), carbon dioxide (CO_2), total hydrocarbons (THC(hot) and (cold)),and nitrogen oxides (NO_x), although any gas analyzer or parameter could be monitored if required. From the above list, the CO and O_2 levels represented the most frequently utilized parameters. Changes in these values initiated a review of each of the incinerator's process control parameters together with a visual inspection of the burning. The system was designed to provide a graphical display of specific gas concentrations to assist in evaluating trends in the process versus emissions.

Visual inspection of the lower furnace burning zone was frequently carried out by the combustion experts to determine whether the burn was occurring evenly on the grates, whether the bed depth on each of the grates was normal, and whether the air supply to each zone was appropriate (ie. the degree of smoking or flame fissures and particulate lift-off rate on each grate zone were noted). If unusual conditions were noted, adjustments to the control system were made to avoid unnecessary variations in the burning rates. Visual inspections were also frequently made using the observation port located at the end of the finishing grates. This view port permitted the observer to see virtually the entire grate zone. Observations of the lower chamber were generally made every half hour with special aspects noted in the log book. During transition periods or periods when abnormal conditions were apparent, observations were made as frequently as every 5 minutes.

Visual inspection of the upper radiation chamber near the boiler inlet was also undertaken periodically by the combustion experts through a refractory-lined inspection port (approximately 20 cm square) to identify any differences between test run types. All notable observations were recorded in the log book, including factors such as the presence of "sparklers" (glowing particles) entering the boiler inlet, the evenness of the flue gas stream (ie. visible flame tips versus a homogeneous glow), and the presence of any large floating material.

Visual inspection of the ash discharged from the quench tank was also part of the lower furnace observation routine. The primary purpose of this exercise was to identify if and when ash quality was deteriorating (ie. when unburned material could be seen). The ash quality was also observed as it was conveyed up the drag chain incline as well as when it was discharged off the end of the conveyor into the ash storage pit below.

Other process aspects which were monitored from time to time by the combustion experts included the following:

- the vertical tube boiler rapping system was inspected daily to ensure that it was functioning normally;

- the electrostatic precipitator voltage and amperage levels were recorded during each test to ensure that there was no malfunction;

- variations in the opacity meter were noted and related to process disturbances (generally little change between tests). Instantaneous opacity readings were recorded continuously (every 30 seconds) by the data acquisition system; and

- main pressure variation in plant steam supply was noted when the steam supply rate fluctuated. Any notable data correlations were noted in the log book.

The previous day's data were reviewed by the combustion experts:

- to determine the level of success that was achieved the previous day with respect to the selected objectives, and

- to establish the operating conditions for the upcoming test.

5.7 DATA ACQUISITION

The data acquisition system was installed at the Quebec City incinerator prior to the Characterization testing and reconnected for the Performance testing. Its purpose was to automatically retrieve process data on a continuous basis, recording readings every 30 seconds. During the test runs, the 30-second readings were stored on the hard disk. Every 5 minutes, a hardcopy printout of the process information was obtained. (Note that these readings were not averages, but updates or "snapshot" readings. Average values were calculated during overnight data processing.) The system could also be requested to recall prior information.

5.7.1 Overview

The data acquisition system monitored virtually all instrumentation installed in the incinerator including:

- the thermocouple grid installed in the radiation chamber and boiler inlet areas;
- the continuous gas analyzers and status;
- the exhaust gas thermocouples and velocity measurement;
- the opacity meter;
- the refuse feed rate;
- combustion air temperatures;
- wet and dry bulb temperatures; and
- the Bailey Network-90 process controller, instrumentation and set-point values.

As shown in Figure 5.6, the system consisted of four microcomputers or "nodes", three IBM-ATs and one IBM-XT, connected in a network. The network made it possible for information on any microcomputer to be accessed by any of the 4 micro computers. Each AT was in turn connected to a datalogging device. Nodes one and two each used a Doric Digitrend C-235 to interface with the instrumentation. Node three was attached to the CIU (Computer Interface Unit) installed on the Bailey Network-90 process controller. Each microcomputer was equipped with a printer and a colour graphics screen. To avoid overcrowding in the process control room, the computers were installed in a separate office.

Data collected by each AT was as follows:

Node 1:   Thermocouple grid and refuse rate;
Node 2:   Continuous gas and other general instrumentation;
Node 3:   Process parameters from the Network-90 process controller.

Node 1 | Node 2 | Node 3

Temperature, Miscellaneous | Continuous Gas | Process Control

Computer | Computer | Computer

Interface

Isotherm Display | Gas Statistic Display | Efficiency Display | Remote Data Display

Manual Data | Data Processing

Summary Reports
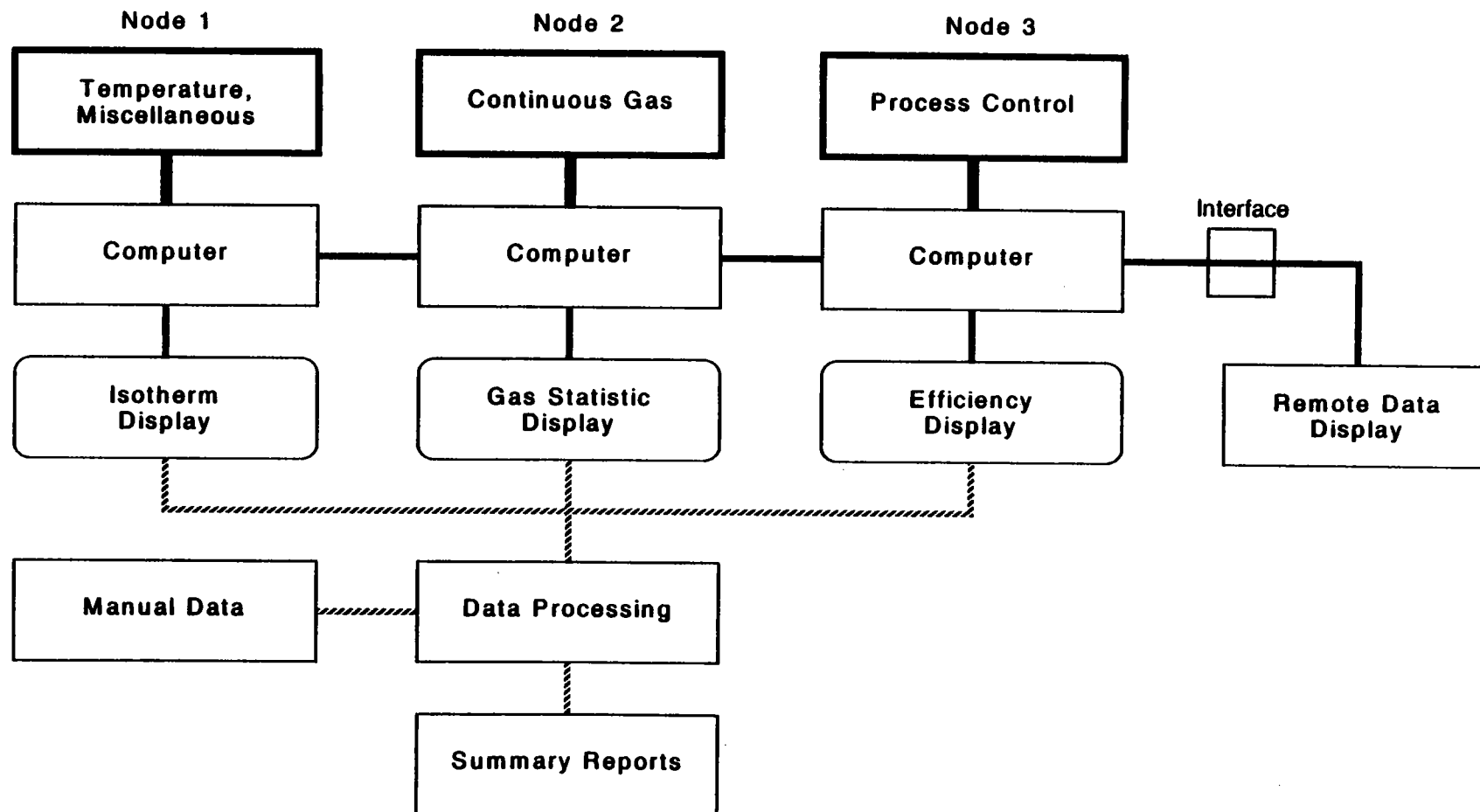
Figure 5.6
QUEBEC INCINERATOR
Data Acquisition System

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Data acquisition software was custom-designed to:

- continuously receive data from the datalogging equipment at 30-second intervals from approximately two hours before the start of each test until the end of the test day;

- convert and store the data in a standard numeric format; and

- display statistics and graphical summaries on a real-time basis.

The programs ran under the QNX operating system (Quantum Software, Ottawa) which provided a fast and reliable environment for real-time applications. These programs would read in the process data, store the information on hard disk, and display the information on screen. In essence two programs were used. The first program was written by Bailey to work with the Bailey process controller and was modified as required by Lavalin. The second was designed specifically to interact with the Doric Digitrend and was written by Lavalin.

The primary objectives in the design of the programs were:

- to ensure that all data received were promptly and correctly stored on the hard disk; and

- to protect the system and data from external problems such as communications breakdowns, power outages and equipment malfunctions.

Other features of the data acquisition programs were:

a) Real-time graphics

Isotherms showing the temperature distribution in either the radiation chamber or the boiler inlet were generated on Node 1. Nodes 2 and 3 featured colour graphs of up to four data points (channels) versus time.

b) Real-time statistical summaries

On each node a second screen displayed statistical summaries consisting of average, maximum, minimum and current values for a preselected subset of data channels and for calculated values. The status of each continuous gas instrument (online, offline, calibrating, etc.) was also shown on this screen.

c) Real-time combustion efficiency

Combustion and steam efficiency calculations, flue gas loss, and excess air based on data monitored by each of the three computers were performed on Node 3.

d) Remote monitoring capability

A remote system from any location could access the data acquisition system and receive statistics from any of the three computers on a real-time basis, via a modem telephone line. Locally, other computers on the QNX network could also use the remote monitoring program to view current data in other locations of the plant such as the operator control room. During the Performance testing, remote monitoring was carried out by the Scientific Authority in Ottawa and interested parties in California.

e) Print-outs

As a precaution, all nodes produced a log print-out of the instantaneous value at each data-point every 5 minutes.

f) Error messages

A third screen displaying program status and all error messages was used for quick diagnosis of any system problem.

This abundance of real-time information proved invaluable to the process engineers for monitoring the progress of the tests.

5.7.2   Node 1 - Temperature Distribution

The software running on Node 1, estimated and displayed isotherms for each scan. For each character position on the screen, the program estimated the temperature at the corresponding location in the incinerator by linearly interpolating from the values of the four closest thermocouples.

In order to create isotherms in the radiation chamber and the boiler inlet, constant waterwall temperature was assumed. Each temperature range (i.e. 400-500°C, 500-600°C) was displayed using one of the eight background colours available on the IBM CGA graphics standard. Relative placement of the thermocouples was also displayed. The program also tested for bad thermocouple values (i.e. negative numbers) and displayed bad thermocouples using a special symbol. The interpolation algorithm was designed to handle up to three neighbouring bad thermocouples.

The second display on Node 1 gave the exact temperature for each thermocouple at each scan, along with grid average, maximum and minimum, and average of the maxima and minima from the start of the test.

Also collected on this node were the real-time field refuse rate. They were made available to Node 3 for use in the efficiency calculations.

5.7.3   Node 2 - Continuous Gas Monitoring

In addition to scanning the continuous gas monitoring equipment, Node 2 also kept track of the current status of each instrument. Each instrument had a corresponding status switch (i.e. Online, Offline, Calibrating and Zeroing) which was set by the continuous gas operator. The current status of each instrument was displayed on the statistical summary screen of Node 2.

The status of each channel was stored with the data channel values for each scan. Using the status settings and the corresponding data values, data processing programs calculated the exact gas concentration measurement at any time. The programs are detailed in Section 5.8.

The current maxima, minima, and averages for nine gas analyzers and the average exhaust temperature were updated and displayed on the statistical screen after each scan. The graphics screen displayed the current value and the trend for the previous hour for four of the channels (i.e. O_2, CO_2, CO, and THC(hot)).

Opacity measurements for the exhaust gases were obtained during each Characterization and Performance Test run by connecting the opacity monitor to the Node 2 data acquisition system.

Exhaust gas flows were also obtained during each test by connecting the pitot pressure transducer and flue gas thermocouple to the Node 2 data acquisition system.

5.7.4   Node 3 - Combustion Efficiency

The real-time calculation of combustion efficiency was performed on Node 3, using some assumptions for data values which could not be measured on a real-time basis (ie. refuse High Heating Value). The efficiency calculation involved data from all three microcomputers:

- refuse feed rate (Node 1);
- percent O_2, CO_2 and CO, exhaust gas temperature and rate (Node 2); and
- steam rate, pressure and temperature (Node 3).

This data was gathered by the program running on Node 3 using the QNX networking capabilities.

Four important process parameters were calculated:

1)   Combustion efficiency,
2)   Flue gas loss,
3)   Excess air, and
4)   Steam efficiency.

These values were recalculated after every scan and the current values displayed on the statistical screen along with the maximum, minimum and average values over the entire test day.

5.7.5 Remote Monitoring of the Real-Time Test Results

The data acquisition software was also designed to communicate with a remote task. This task could be initiated by logging in through a modem or using the IBM-XT through the QNX network. Remote monitoring featured the identical statistical summary screen available in the computer room and was used extensively by the Scientific Authority (SA) in Ottawa to receive up-to-date test data at 30-second intervals. A computer screen was also installed in the operator's control room. This provided the process engineers with a real-time report of data (such as continuous gas data) which was not available from the process control system. This proved invaluable for the quick identification of process upsets.

5.7.6 Daily Operation of the Data Acquisition System

The daily operation of the data acquisition system was recorded in the computer room log book. Test and traverse start and end times were recorded as well as all normal and any abnormal computer set-up and operations. Tasks for a typical test day include:

Before test start-up:

1) Verify or set the clock of each AT to correspond with the official test clock

2) Boot systems (i.e. start the computer) under the QNX operating system and ensure that sufficient disk space for the day's test results is available.

3) Start Node 2 (continuous gas) and notify the continuous gas personnel that equipment calibrations can commence.

4) Start the other nodes. Ensure that the conversion function used for all data points on the Doric dataloggers were completely re-initialized from the stored set-up files.

5) Ensure that there is an adequate supply of paper for log print-outs and that the printers are functioning properly.

Daily Operation:

6) Record the start and stop times of each traverse.

7) Monitor values, check for process upset conditions.

8) Regulate computer problems between traverses if necessary, or otherwise allow computers to continue recording all incoming data.

At Test Completion:

9) Immediately stop all logging except on Node 2 (continuous gas).

10) Shut-down Node 2 once all continuous gas equipment has been recalibrated.

11) Back up all data to a second location on the hard disk and to a back-up storage tape.

5.8   DATA PROCESSING

Data processing involved reworking the data retrieved during the test runs into a more meaningful form, i.e., producing 5- and 15-minute averages, creating graphics revealing trends in process parameters and producing a summary report. During this procedure and upon examination of the results, any problems were identified, noted, and accounted for. By processing the data immediately after each test run, any required corrections or adjustments to either equipment or methodologies were made prior to the following test run.

5.8.1   General

A very extensive array of data was collected during the Characterization and Performance Test series at the Quebec City Incinerator. All data collected by the data acquisition system and by hand were stored and analyzed using micro-computer programs. Many security features were built into these systems to guard against accidental loss of data.

Data processing for each test was carried out overnight. Datalogger output and manual field sampling data were processed, graphs and summary sheets were produced, and corrections to previous test results were made as required. Figure 5.7 illustrates the data handling functions of the night-shift.

Four microcomputers were in constant use (three IBM-AT's and one IBM-XT). All files produced were backed up in DOS format onto a 60 Megabyte backup tape drive. Files were uploaded or downloaded between the tape drive, and transferred between the four computers using the QNX network.

Several other functions performed by the night-shift included editing problem datafiles and recreating lost or damaged scans using the raw data print-outs produced during the test runs. From the printed hardcopy output, it was possible to recreate every 10th scan over a missing time period. Any problems or comments noted were recorded in a log book. These comments were in turn reviewed by the Test Coordinator the following morning, and suitable instructions relayed back to the data processing engineers.

The overnight turnaround of data greatly assisted the Test Crew in evaluating the success of previous tests and establishing new parameters for following tests. Any comments from the quality control

Field Data Sheets

Computer

Field Instrumentation → Data Logger → Computer → Data Verification → Data Processing

Print Out

Raw Data
First and Second
Level Average

Print Out

Summary Process
and Sampling
Sheets
Graphic of
Relevant Data
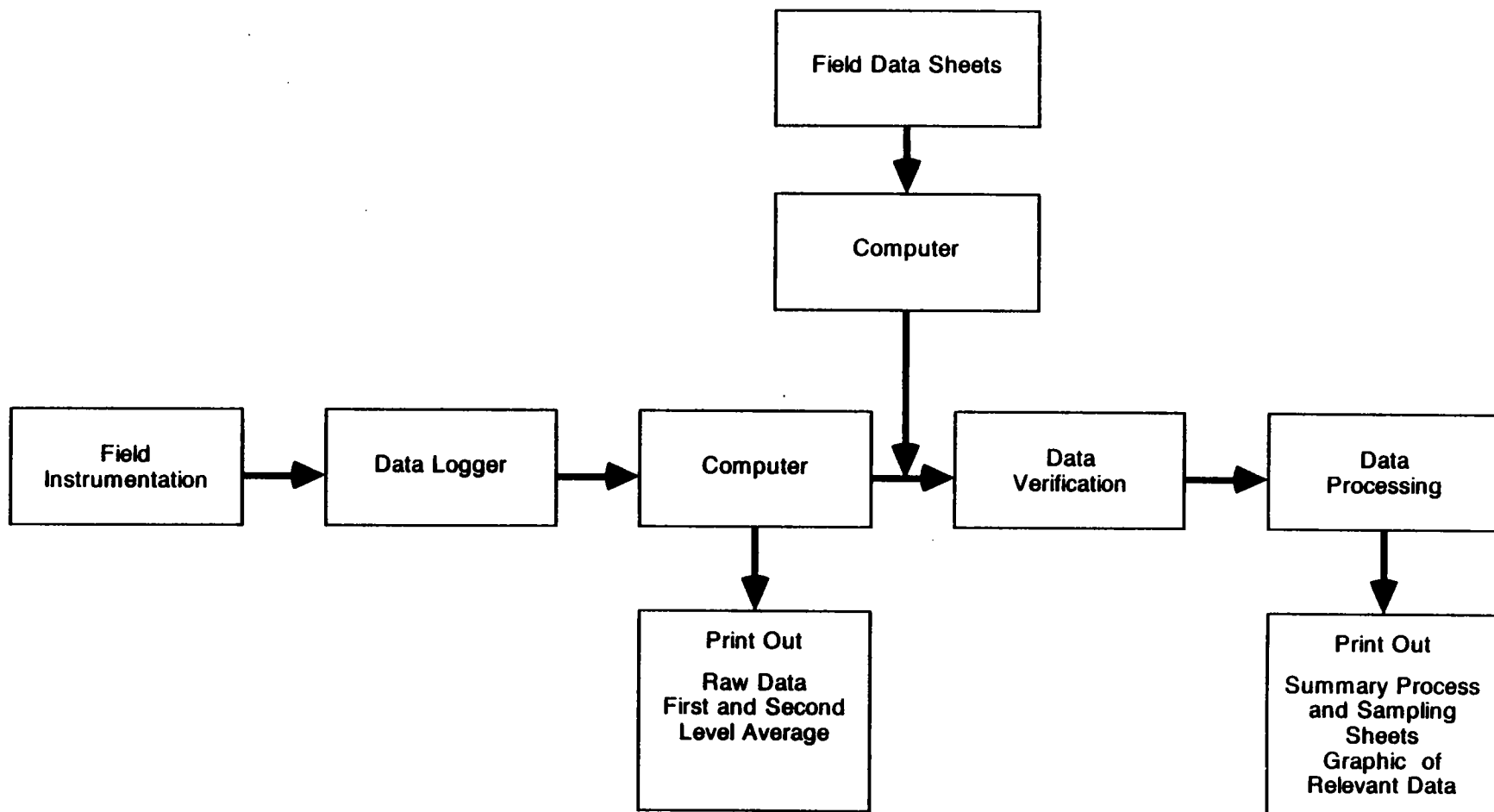
Figure 5.7
QUEBEC INCINERATOR
Field Data Handling Diagram

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personnel were reviewed and corrected the following day. In this manner, many potential problems were avoided in the field.

The following sub-sections in this chapter describe the type of data obtained, the data processing procedures, and the resultant formats of the data after manipulation.

5.8.2   Datalogger Output

The basic data processing procedures were similar for all three dataloggers, and are summarized as follows:

- The raw datafiles collected during the day were filtered to discard scans outside the desired time periods. Various factors were applied to some of the channel values which required unit conversions. For example, the continuous gas monitors provided voltage readings which were converted to concentration readings.

- The filtered datafiles were put through statistical routines to calculate channel averages, maxima, minima, variances and standard deviations. Averages were calculated over 5-, 15-, 30- and 60-minute intervals.

- Summary reports were generated. (Examples of the raw data and summary sheet for PT-05 can be found in Volume IV.)

- The filtered files from all three dataloggers were then combined in a random access binary matrix which allowed the selection of any channel combination from any of the three dataloggers for graphic purposes.

- The filtered files, channel matrix files, and report files were backed up onto tape.

A number of computer programs were developed to process the output from these three dataloggers. Although the basic processing steps were similar, individual programs had to be tailored for each specific datalogger due to differences in data file format and channel assignments. Figure 5.8 outlines the processing steps performed by the various computer programs.

The principal features of the computer algorithms used during the data processing were:

Datalogger #1 - Thermocouples

Bad thermocouple readings were indicated as such (i.e. "bad values" -9999.9) by the filter program. These conditions included broken thermocouples, all negative temperatures, and unusually cool radiation chamber and boiler inlet temperatures (less than $341^\circ C$)·

Thermocouples *Datalogger #1*

Instrumentation *Datalogger #2*

Bailey Process Control *Datalogger #3*

Raw Data QNX

QDOS Transfer

Raw Data DOS

FILTER.BAS
Filter Routines

Filtered Data DOS

THERMO.BAS
Statistical Routines

Raw Data QNX

QDOS Transfer

Raw Data DOS

FILTER.BAS
Filter Routines
Calibration Routines

Calibration Matrix Report

Filtered Data DOS

GASRPT.BAS
Statistical Routines

Raw Data QNX

MAKE.BAILEY.C
Filter Routines

QDOS Transfer

Filtered Data DOS

BAILRPT.BAS
Statistical Routines

GRAPHMAT.BAS
Channel Consolidation

Reports

Random Access File Channel Matrix

Reports

Reports

Graphics

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Figure 5.8
QUEBEC INCINERATOR
Datalogger Processing Steps

Datalogger #2 - Instrumentation

Unusually cool exhaust gas temperatures (less then 150°C) were flagged as bad values (-9999.9) by the filter program. Instrumentation readings which indicated unusually high or low gas concentrations were also identified as bad values, as follows:

i)	carbon monoxide	<3 ppm
ii)	carbon dioxide	<2 %
iii)	oxygen	<2 % or 20 %
iv)	sulfur dioxide	<25 ppm
v)	nitrogen oxide	<25 ppm
vi)	hydrogen chloride	<100 ppm

The calibration algorithm calculated a linear equation for each instrument over each time interval, based on the most recent zero and calibration for each instrument. The linear equations were used to convert voltages to concentration units during on-line status. The opacity readings were multiplied by a factor to convert voltage to percent opacity. Each reading was adjusted for 12% carbon dioxide (CO_2).

Datalogger #3 - Process Control Data

The computer process control datalogger indicated the status mode of each analog and digital channel with a corresponding seven-digit binary code, as follows:

i)	Setpoint Tracking	- position 1
ii)	Red Tag	- position 2
iii)	Deviation Alarm	- positions 3 and 4
iv)	Limit Alarm	- positions 5 and 6
v)	Quality	- position 7

A measured value whose seven-digit binary code was less than 128 was considered to be a good value, and the value of the status code was retained in the 2-digit unit field of the filter file for future reference. If the binary code was zero, then the unit field in the filter file was left blank.

A measured value whose seven-digit binary code exceeded 128 was distinguished by the filter program as a bad value (-9999.9), and a value of 01 was written in the 2-digit unit field of the filter file.

5.8.3   Datalogger Summary Report

The reports from the data processing for the three dataloggers included the following:

● the Calibration Matrix report for datalogger #2, documenting the detailed history of the state of the nine continuous stack gas monitoring instruments over the duration of the test (ie: on-line, off-line, calibrating, or zeroing);

- the Interval Average reports for each datalogger, displaying the 5-, 15-, 30- and 60-minute averages of selected channels over the duration of the test;

- the Channel Descriptions and Statistics report for each datalogger, displaying the average, maximum, minimum, variance and standard deviation for every channel. The times at which each maximum and minimum value was encountered were also recorded to facilitate error analysis.

- the Summary reports for each datalogger, included the boiler inlet temperature grid pattern (DL #1), the continuous flue gas analysis summary (DL #2), and the summary presentation of steam characteristics, primary and secondary airflow distributions, grate speeds, and incinerator temperatures (DL #3).

Examples of the summary reports can be found in Volume IV.

5.8.4   Manual Sampling Data

Manual sampling train data were recorded for particulates, metals, trace organics, particle size distribution, acid gases, and mercury. Measurements were recorded on field sheets which were drawn up in accordance with standard reference methods or manuals provided with individual sampling systems, or modified as necessary for each specific application. The format of all field sheets were reviewed by the Scientific Authority and QA/QC coordinators prior to commencement of the field program.

Each field sheet was identified with a standard heading which clearly indicated the test number, test date, the operator(s)'s name(s) and the signing QA/QC authority. A copy of each of these field sheets is included in Volume IV.

Following the completion of each Characterization and Performance Test, all sampling train data and field data sheets were catalogued and checked for errors or omissions. All of the sheets for a particular run were secured in a single file folder with two-hole punch fasteners. The file folders were secured in the filing cabinet inside the locked computer control room, and were available for review only by designated test personnel.

The data on the sampling train field sheets were keypunched into the computer (along with sample recovery data from the field laboratory) and processed overnight using approved isokinetic and particle size computer programs.

5.8.5   Summary Sheets

The data summary sheets were created using spreadsheets, thus ensuring easy modification of format to suit subsequent reporting requirements. Two summary sheets were filled out at the end of each

night-shift, presenting all of the pertinent test parameter results for both manual field sampling and computer monitored instrumentation. Examples of the summary sheets are presented in Tables 5.5, 5.6, and 5.7.

The Instrumentation Summary sheet presented the following:

- steam flow rate, pressure and temperature;

- refuse feed rate, and the steaming ratio expressed as the ratio of steam production over refuse consumed;

- incinerator efficiency, calculated in terms of combustion, steam production, and BTU production;

- flow rates for primary, secondary and total combustion air, and for the exhaust stack;

- thermocouple temperatures in the primary and secondary air supply ducts, the upper and lower incinerator chamber, the boiler inlet screen tubes and the exhaust stack; and

- flue gas analysis from the ten continuous monitoring instruments.

The Field Summary sheet presented the following:

- several parameters associated with the refuse and plastics sampling, including sample weight and sampling duration;

- flow rates for the incinerator, boiler/economizer and precipitator ashes, also expressed as a percentage of refuse input;

- several parameters associated with the organic, mercury, metals/particulates and particle size/HCl sampling trains, including sampling irregularities or sample recovery problems, maximum leak check rate, total sample volume, moisture content, flue gas flow and temperature, and isokineticity.

5.8.6 Graphics

A large number of graphics were produced overnight for some of the more important trends for each run. Software was designed to integrate with "off-the-shelf" graphics software to facilitate tailor-made graphics. The software allowed the data processing engineer to select the following:

- channel combinations to be graphed;
- time interval for the averaging of data (5 or 15 minutes);
- traverse or time interval under consideration;
- graph headings, axis titles, and axis scale factors.

TABLE 5.5 INSTRUMENT SUMMARY SHEET

NITEP - QUEBEC   TEST RUN AVERAGES

		PT01	PT02	PT03	PT04	PT05	PT06	PT07	PT09	PT10	PT11	PT12	PT13	PT14	PT15
PERFORMANCE TEST #:															
TEST DATE:	U	860626	860627	860628	860629	860630	860702	860703	860705	860706	860707	860702	860710	860711	860712
TEST START:	N	12:30:00	12:30:00	10:35:00	10:30:00	10:50:00	10:10:00	10:10:00	9:40:00	9:35:00	9:15:00	10:05:00	10:30:00	10:30:00	9:30:00
TEST FINISH:	I	20:15:00	20:50:00	19:25:00	18:25:00	20:50:00	17:18:00	17:54:00	17:00:00	16:40:00	16:29:00	16:40:00	19:12:00	18:10:00	17:45:00
TEST TRAVERSE LENGTH:	T	60 min	64 min	80 min	80 min	80 min	64 min	64 min	80 min	80 min	80 min	80 min	*80 min	80 min	80 min
TEST LOAD TYPE:	S	LOW	LOW	DESIGN	DESIGN	DESIGN	DESIGN	HIGH	HIGH	LOW	LOW	DESIGN	HIGH	DESIGN	DESIGN
TEST TEMPERATURE RANGE:		LOW	LOW	LOW	LOW	DESIGN	DESIGN	DESIGN	DESIGN	LOW	LOW	DESIGN	DESIGN	LOW	LOW
OPERATION CONDITION:		PRELIM.	GOOD	POOR	POOR	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	BAD	BAD
Steam Rate (Tonnes/hr)	tonne/hr	20.1	20.0	28.1	27.8	28.0	28.1	31.8	31.8	20.0	20.0	27.9	31.6	28.5	28.3
Steam Pressure (kPa)	kPa	4260	4244	4308	4315	4307	4297	4396	4420	4365	4265	4313	4345	4328	4317
	Psia	597	595	604	605	604	602	616	619	612	598	604	609	607	605
Steam Temp. (calc. from press.)	F	489	490	488	488	488	488	486	485	487	489	488	487	488	488
	C	254	254	253	253	253	254	252	252	253	254	253	253	253	253
Steam Temperature (measured)	C	318	318	323	323	321	321	323	325	326	323	323	324	322	321
Refuse Feed Rate	tonne/hr	6.8	6.2	10.1	9.0	8.7	8.7	8.6	10.8	6.5	6.7	9.3	11.3	8.4	9.0
Steaming Ratio (TonneSt/TonneRef)		2.96	3.20	2.79	3.07	3.22	3.24	3.69	2.94	3.09	3.00	3.00	2.80	3.39	3.16
Moisture in Gas [AVG 3 TRAINS]	X	11.6	13.4	14.1	13.1	15.8	16.4	13.8	16.1	11.9	13.3	14.7	15.2	12.5	14.1
Efficiencies:															
-Combustion	X	99.924	99.986	99.937	99.933	99.983	99.978	99.964	99.964	99.980	99.975	99.969	99.936	99.872	99.856
-Steam [from bailey]	X	BV/NA	BV/NA	BV/NA	57.41	64.69	64.80	69.13	62.47	55.74	56.60	77.69	72.86	79.42	81.33
-Input Btu/Output Btu		62.8	67.9	59.2	65.2	68.3	68.7	78.2	62.3	65.6	63.7	63.5	59.4	71.8	66.9
Flows:															
-Flue Gas (DRY STANDARD) [3T's]	Sm3/min	960	874	1130	1156	828	844	945	985	910	875	953	1036	1055	1046
-Flue Gas [AVG 3T's]	Am3/min	1744	1625	2254	2319	1613	1679	1840	2012	1719	1668	1913	2143	2068	2073
-Total Comb. Air [Bailey]	Am3/min	525	477	918	960	546	541	625	750	553	498	550	725	540	555
-Primary Air [Bailey]	Am3/min	119	279	555	583	356	346	307	450	291	313	366	455	474	494
-Secondary Air [Bailey]	Am3/min	406	198	362	377	190	194	318	300	261	186	184	270	67	61
Combustion Air Distribution:															
-Primary Ratio		23	59	61	61	65	64	49	60	53	63	67	63	88	89
-Secondary Ratio		77	41	39	39	35	36	51	40	47	37	33	37	12	11
-Secondary Front/Rear Ratio		57:43	42:58	47:53	50:50	39:61	31:69	60:40	64:36	56:44	44:56	42:58	64:36	26:74	25:75
Temperatures (deg C) :															
-Lower Incinerator [F/R avg]	C	842	849	861	856	1014	1030	1085	1006	875	869	992	997	991	964
-Lower Front Incinerator	C	849	849	860	858	1023	1049	1088	1005	877	866	1000	1010	1010	977
-Lower Rear Incinerator	C	835	849	862	853	1004	1011	1082	1006	873	871	983	984	971	950
-Upper Incinerator [F/R avg]	C	618	637	672	655	777	774	839	791	688	688	793	799	747	718
-Upper Front Incinerator	C	589	603	645	627	742	737	805	743	653	651	754	759	704	670
-Upper Rear Incinerator	C	647	671	698	683	812	811	872	838	722	725	831	838	789	766
-Primary & Secondary Avg.	C	35	32	36	33	35	32	31	26	29	34	34	28	32	32
-Primary Air	C	38	30	35	31	33	30	30	25	29	32	31	27	27	27
-Secondary Air	C	33	34	37	34	37	34	31	27	30	35	36	30	37	38
-Boiler Inlet	C	698	712	724	700	813	817	836	810	688	689	785	769	745	762
-Stack	C	201	199	230	232	206	212	220	233	212	212	225	240	232	228
-Flue Gas Average [3 Trains]	C	205.1	202.8	230.3	237.4	209.4	216.8	221.2	236.7	214.7	216.4	229.5	245.1	235.3	232.6
Continuous Flue Gas Data [corr.12% CO2]:															
Carbon Dioxide	X	7.6	7.6	8.5	7.9	11.1	11.1	10.3	10.5	7.5	7.7	9.2	9.8	8.3	8.8
Carbon Monoxide	PPMC	91.8	16.5	76.0	79.9	20.4	26.6	42.7	43.3	24.2	29.7	36.7	77.3	153.3	173.4
Oxygen (dry basis)	X	12.7	12.6	12.0	12.2	8.8	9.2	9.8	9.8	12.9	12.0	10.3	10.3	11.6	11.3
THC cold	PPMC	5.8	2.3	2.0	2.2	1.4	1.8	1.8	1.5	2.5	2.2	2.1	1.5	3.1	3.0
THC hot	PPMC	7.9	6.0	3.0	5.5					4.0	5.3	4.3			1.9
SO2	PPMC	203.3	159.5	145.2	159.7	178.3	185.9	191.9	127.9	209.0	175.0	225.1	178.0	161.7	150.7
NO2	PPMC	206.6	231.6	223.9	245.8	171.8	169.3	185.5	201.9	191.0	191.5	199.2	205.1	191.0	182.7
HCL	PPMC	383.9	564.8		453.1	503.7	365.6	512.1	369.3	465.3	465.9	487.3	499.7	594.1	446.6
Excess Air	X	146.3	143.1	128.7	132.1	69.4	75.5	84.2	84.6	152.7	125.8	91.2	92.5	117.3	111.4
Opacity	X	28.6	26.1	34.5	36.1	32.0	29.0	35.4	29.6	30.9	30.0	38.9	36.3	36.2	34.7

TABLE 5.6 FIELD SUMMARY SHEET

NITEP - QUEBEC CITY   FIELD SHEET SUMMARY

PERFORMANCE TEST #:			PT01	PT02	PT03	PT04	PT05	PT06	PT07	PT09	PT10	PT11	PT12	PT13	PT14	PT15
DATE:			860626	860627	860628	860629	860630	860702	860703	860705	860706	860707	860702	860710	860711	860712
TEST START:			12:30:00	12:30:00	10:35:00	10:30:00	10:50:00	10:10:00	10:10:00	9:40:00	9:35:00	9:15:00	10:05:00	10:30:00	10:30:00	9:30:00
TEST FINISH:			20:15:00	20:50:00	19:25:00	18:25:00	20:50:00	17:18:00	17:54:00	17:00:00	16:40:00	16:29:00	16:40:00	19:12:00	18:10:00	17:45:00
TEST LOAD TYPE:			LOW	LOW	DESIGN	DESIGN	DESIGN	DESIGN	HIGH	HIGH	LOW	LOW	DESIGN	HIGH	DESIGN	DESIGN
TEST TEMPERATURE RANGE:			LOW	LOW	LOW	LOW	DESIGN	DESIGN	DESIGN	DESIGN	LOW	LOW	DESIGN	DESIGN	LOW	LOW

			PT01	PT02	PT03	PT04	PT05	PT06	PT07	PT09	PT10	PT11	PT12	PT13	PT14	PT15
3 - Refuse Charging	Refuse Charging Rate:	kg/h	6789	6245	10056	9043	8696	8673	8618	10826	6463	6661	9308	11286	8417	8967
	Total Weight Loaded	kg	79210	71815	99385	83650	107110	76610	75405	83360	47935	48850	66705	116250	71545	77865
	Sampling Duration:	h	11.7	11.5	9.9	9.3	12.3	8.8	8.8	7.7	7.4	7.3	7.2	10.3	8.5	8.7
4 - Refuse Shredding	Total Sample Weight	kg	2147	2797	3598	3348	3881	1802	3063	2338	4118	3473	3147	3258	3969	3228
	Sampling Duration:	h	9.7	7.7	9.2	7.7	7.7	7.1	7.5	4.4	8.4	3.7	7.4	7.4	12.1	7.7
4 - Refuse Reject	Glass	kg	70.7	20.9	33.4	17.3	20.3	10.9	11.1	5.9	21.0	18.8	51.5	20.6	24.3	15.9
	Metal	kg	50.1	26.3	31.5	18.8	10.4	94.5	33.6	40.9	25.8	53.7	83.8	108.6	74.1	15.4
	Other	kg	81.1	37.5	50.3	12.9	11.0	28.1	8.6	84.5	66.8	111.8	221.9	60.2	142.7	150.6
	Other Other	kg			17.6	17.6		14.0	13.9	13.9	1.8	14.2	81.0	7.7	41.7	12.3
	Total Rejects - net weight	kg	202	85	133	67	42	147	67	145	115	199	438	197	283	194
4A - Plastics Sampling	Total Sample Weight	kg	562	BV/NA	1180	BV/NA	683	BV/NA	887	626	BV/NA	752	BV/NA	353	441	BV/NA
	Sorted Sample Weight	kg	53	BV/NA	83	BV/NA	70	BV/NA	81	59	BV/NA	45	BV/NA	40	28	BV/NA
6 - Incinerator Ash	Ash rate	kg/h	3131	1728	3255	3022	3421	3202	3618	3222	2820	1825	2862	3687	2734	3621
	Percent Refuse Input	(%)	46.1	27.7	32.4	33.4	39.3	36.9	42.0	29.8	43.6	27.4	30.7	32.7	32.5	40.4
	Four Quench Tank Sub-samples	(check)	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
7 - Boiler/Economizer	Ash rate	kg/h	20.2	29.4	30.7	38.4	33.5	24.4	41.5	58.9	36.6	33.3	44.0	62.0	57.3	42.9
	Percent Refuse Input	(%)	0.3	0.5	0.3	0.4	0.4	0.3	0.5	0.5	0.6	0.5	0.5	0.5	0.7	0.5
7 - Precipitator Ash	Ash rate	kg/h	35.6	46.0	131.6	131.0	47.0	54.2	65.8	92.4	46.6	43.5	71.0	128.4	121.8	110.8
	Percent Refuse Input	(%)	0.5	0.7	1.3	1.4	0.5	0.6	0.8	0.9	0.7	0.7	0.8	1.1	1.4	1.2

TABLE 5.7 FIELD SUMMARY SHEET

NITEP - QUEBEC CITY   FIELD SHEET SUMMARY

		PT01	PT02	PT03	PT04	PT05	PT06	PT07	PT09	PT10	PT11	PT12	PT13	PT14	PT15
PERFORMANCE TEST #:															
DATE		860626	860627	860628	860629	860630	860702	860703	860705	860706	860707	860702	860710	860711	860712
TEST START		12:30:00	12:30:00	10:35:00	10:30:00	10:50:00	10:10:00	10:10:00	9:40:00	9:35:00	9:15:00	10:05:00	10:30:00	10:30:00	9:30:00
TEST FINISH		20:15:00	20:50:00	19:25:00	18:25:00	20:50:00	17:18:00	17:54:00	17:00:00	16:40:00	16:29:00	16:40:00	19:12:00	18:10:00	17:45:00
TEST LOAD TYPE		LOW	LOW	DESIGN	DESIGN	DESIGN	DESIGN	HIGH	HIGH	LOW	LOW	DESIGN	HIGH	DESIGN	DESIGN
TEST TEMPERATURE RANGE		LOW	LOW	LOW	LOW	DESIGN	DESIGN	DESIGN	DESIGN	LOW	LOW	DESIGN	DESIGN	LOW	LOW
9 - Organic Train															
Any Sampling Irregularities	(yes/no)	yes	no	yes	no	no	no	yes	no	no	no	no	yes	no	no
Maximum Leak Check Rate	ft.3/min	0.020	0.045	0.019	0.020	0.019	0.014	0.140	0.012	0.010	0.009	0.007	0.015	0.018	0.018
Total Sample Volume	Sm3	1.41	2.54	4.18	4.32	3.14	3.49	3.93	3.81	3.35	3.36	3.61	3.88		
Moisture content	%	10.84	12.61	13.58	12.85	16.73	15.80	13.56	16.05	11.95	13.27	14.66	15.01	12.27	14.08
Flue gas flow	Sm3/s	16.54	15.32	19.42	20.15	14.30	14.70	16.73	17.08	15.92	15.71	16.70	17.99	18.33	17.82
Flue gas flow	Sm3/hr	59544	55145	69915	72536	51481	52932	60227	61474	57327	56538	60128	64770	66002	64144
Flue gas flow	Am3/hr	106793	101262	138938	144295	100988	103877	116948	125230	108230	107250	119755	133049	128637	126353
Flue gas temperature	C	203.1	200.9	231.3	234.5	207.8	213.9	221.1	235.3	214.2	214.1	225.9	242.5	233.5	229.7
Isokineticity	%	102.9	97.4	101.8	99.8	102.4	99.0	97.5	103.5	98.3	98.4	101.9	100.5	95.9	101.5
9 - Mercury Train															
Any Sampling Irregularities	(yes/no)	no	no	yes	no	no	no	no	no	no	no	no	no	no	no
Maximum Leak Check Rate	ft.3/min	0.011	0.012	0.018	0.012	0.004	0.005	0.012	0.006	0.012	0.005	0.010	0.016	0.017	0.003
Total Sample Volume	Sm3	3.84	3.76	6.20	6.30	4.67	3.86	4.06	5.52	4.87	4.75	5.32	5.35	5.84	5.89
Moisture content	%	11.82	14.19	14.22	13.49	16.81	16.70	13.92	16.15	11.85	13.10	14.51	15.18	12.44	13.98
Flue gas flow	Sm3/s	15.91	13.76	18.30	18.73	13.26	13.40	15.13	16.04	14.66	13.89	15.38	16.68	17.21	17.11
Flue gas flow	Sm3/hr	57273	49545	65887	67427	47745	48246	54457	57733	52766	49999	55381	60062	61958	61588
Flue gas flow	Am3/hr	104503	93221	131517	136278	94311	96587	106245	118197	99320	95152	111130	124504	121564	122093
Flue gas temperature	C	206.1	203.8	229.8	238.9	210.7	218.3	221.3	237.3	213.2	216.6	230.6	246.1	235.9	233.5
Isokineticity	%	95.4	101.4	100.6	99.8	104.4	106.7	99.5	102.2	98.5	101.5	102.8	102.4	100.7	102.2
9 - Metals/Particulate															
Any Sampling Irregularities	(yes/no)	no	no	yes	no	no	no	no	no	no	no	no	no	no	no
Maximum Leak Check Rate	ft.3/min	0.011	0.035	0.013	0.020	0.016	0.014	0.011	0.013	0.012	0.010	0.004	0.005	0.010	0.008
Total Sample Volume	Sm3	3.63	3.78	6.07	6.06	4.56	3.78	3.90	5.30	4.77	4.75	5.23	5.26	5.72	5.76
Moisture content	%	12.28	13.38	14.47	13.07	13.96	16.80	13.79	16.06	11.97	13.52	14.98	15.44	12.66	14.34
Flue gas flow	Sm3/s	15.53	14.60	18.77	18.90	13.84	14.10	15.40	16.13	14.91	14.16	15.56	17.11	17.20	17.36
Flue gas flow	Sm3/hr	55917	52576	67569	68034	49818	50763	55447	58062	53672	50988	56033	61597	61927	62513
Flue gas flow	Am3/hr	102604	97942	135262	136867	94968	101748	107991	118787	101851	97885	113392	128205	121978	124737
Flue gas temperature	C	206.2	203.6	229.8	238.9	209.8	218.3	221.2	237.5	216.6	218.5	232.0	246.6	236.6	234.7
Isokineticity	%	94.9	98.6	98.5	97.6	100.3	102.0	96.5	100.1	97.5	102.2	102.2	100.9	101.3	101.0
9 - HCl															
Any Sampling Irregularities	(yes/no)	yes	yes	no	no	no	no	no	no	no	no	no	no	no	no
Maximum Leak Check Rate	ft.3/min	0.090	0.020	0.004	0.001	0.003	0.004	0.002	0.007	0.006	0.005	0.004	0.006	0.000	0.002
Total Sample Volume	Sm3	3.06	3.33	1.88	0.90	2.86	2.26	1.76	2.46	3.04	2.41	2.18	1.36	0.96	1.19
Moisture content	%	12.89	14.28	14.55	12.43	15.76	16.67	13.68	15.68	11.89	13.34	14.92	15.64	12.69	13.89
Flue gas flow	Sm3/s	14.70	13.43	18.32	20.86	13.17	13.28	14.54	16.02	14.76	13.86	15.52	17.46	18.68	18.58
Flue gas flow	Sm3/hr	52906	48333	65967	75094	47428	47823	52338	57659	53126	49879	55873	62844	67248	66882
Flue gas flow	Am3/hr	96277	89498	129890	148756	90852	93507	100038	115630	98670	92908	110003	127792	130256	130910
Flue gas temperature	C	199.0	195.8	221.1	234.9	201.9	207.0	212.6	229.6	206.5	204.9	218.7	233.5	228.0	227.7
Isokineticity	%	104.7	115.0	112.4	113.5	112.6	98.4	95.3	96.4	100.0	107.2	98.9	102.7	100.4	105.7
10 - Particle Size															
Any Sampling Irregularities	(yes/no)	yes	yes	no	no	no	no	no	no	no	no	no	no	no	no
Maximum Leak Check Rate	ft.3/min	0.090	0.020	0.004	0.001	0.003	0.004	0.002	0.007	0.006	0.005	0.004	0.006	0.000	0.002
Total Sample Volume	Sm3	3.06	3.33	1.88	0.90	2.86	2.26	1.76	2.46	3.04	2.41	2.18	0.82	0.96	1.19
Moisture content	%	12.89	14.28	14.55	12.43	15.76	16.67	13.68	15.68	11.89	13.34	14.92	15.64	12.69	13.89
Flue gas flow	Sm3/s	14.70	13.43	18.32	20.86	13.17	13.28	14.54	16.02	14.76	13.86	15.52	17.39	18.68	18.58
Flue gas flow	Sm3/hr	52906	48333	65967	75094	47428	47823	52338	57659	53126	49879	55873	62603	67248	66882
Flue gas flow	Am3/hr	96277	89498	129890	148756	90852	93507	100038	115630	98670	92908	110003	127344	130256	130910
Flue gas temperature	C	199.0	195.8	221.1	234.9	201.9	207.0	212.6	229.6	206.5	204.9	218.7	233.5	228.0	227.7
Isokineticity	%	104.7	115.0	112.4	113.5	112.6	98.4	95.3	96.4	100.0	107.2	98.9	103.6	100.4	105.7

Before printing any graphs on the plotter, each graph was reviewed on screen and corrected where required. For each graph, a file was created storing all data and graph specifications. From these files, any graph could be immediately re-created at any time.

Data for up to six different components could be displayed on one graph. However, this much information created a graph that was too cluttered, so a maximum of three types of data was limited to one graph. Two scales (left and right) were provided when necessary. Figure 5.9 presents a typical graph utilizing both left- and right-hand scales.

Mainly, process parameters and component concentrations were graphed over time. Typically, the following series of graphs were produced each night:

i) CO_2 (ppm) and THC(hot and cold) (ppm) over time (min);

ii)   HCl (ppm), SO_2 (ppm), and NO_x (ppm) over time (min);

iii) CO_2 (%), O_2 (%), and opacity (%) over time (min);

iv)   average temperatures - lower, upper, boiler inlet (^{o}C) over time (min);

v)   total air (m^3/min), primary air/total air (%), and flue gas flow (m^3/min) over time (min);

vi)   steam (tonnes/hr) and drying/burning grate speed over time (min);

vii) steam (tonnes/hr), drying grate speed (%), and burning grate speed (%) over time (min);

viii) drying/burning grate speed and CO_2 (ppm) over time (min);

ix)   drying/burning grate speed versus CO_2 (ppm); and

x)   30-second readings of drying and burning grate speeds (%) over time (min). Only a few 30-second graphs were produced.

5.9   EQUIPMENT CALIBRATION

Several pieces of equipment were calibrated by standard procedures prior to and after use in the field. The calibration procedures had been discussed with and approved by the SA and Environment Canada's Quality Assurance/Quality Control (EC QA/QC). The appropriate calibration sheet(s) had been submitted to the contractor QA/QC for approval and transmitted to EC QA/QC.

Volume III contains the appropriate calibration documentation.

5.9.1   Scales

A total of four scales were used on-site, consisting of two different types. The first type weighed the refuse feed - a weigh scale platform with 4 load cells, previously described in Section 4.1.2. It was

Drying Grate/Burning Grate and CO
5-Minute Averages
RUN : PT11
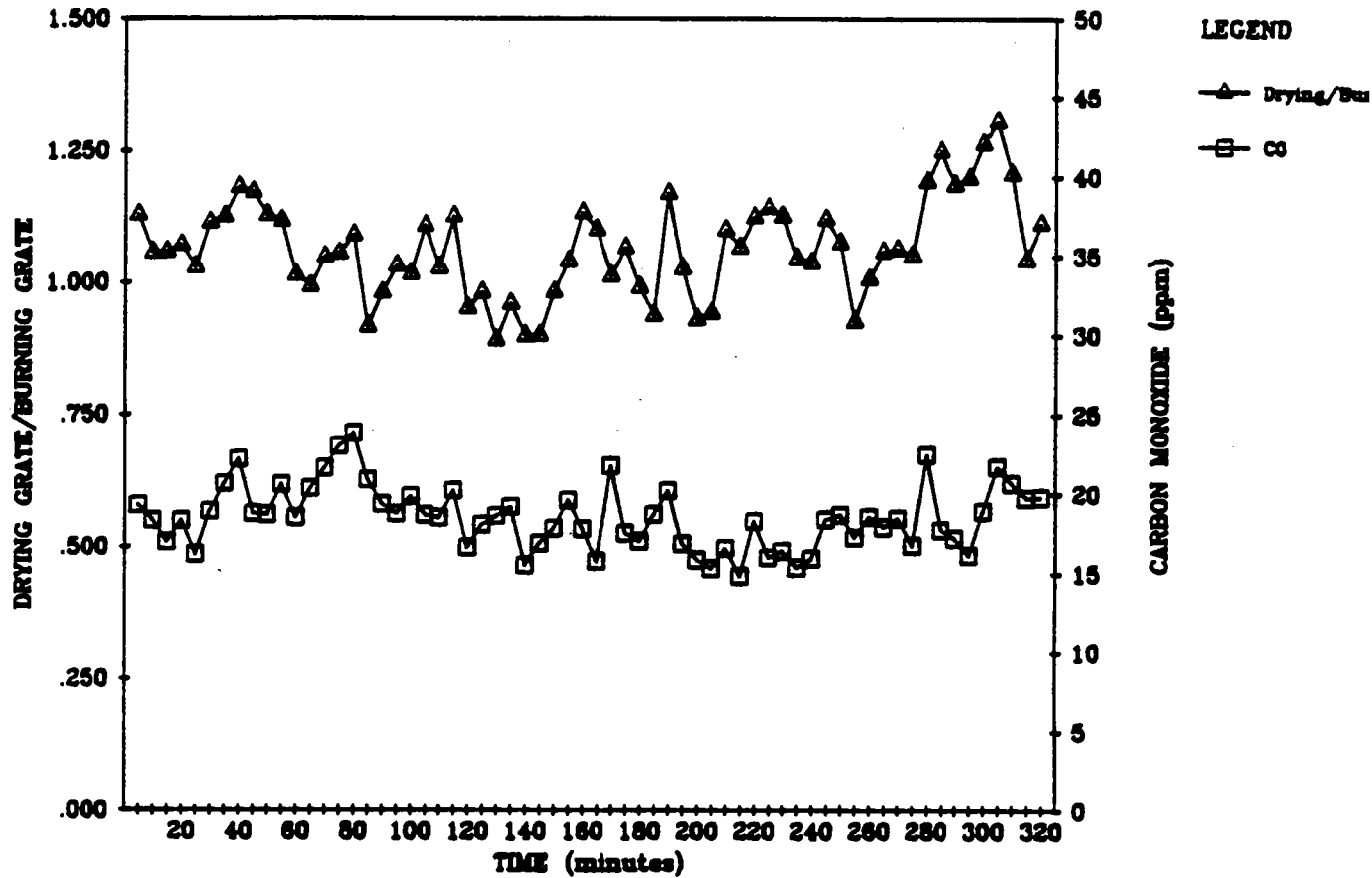
Figure 5.

QUEBEC INCINERATOR

Example of a Two-Scale Graph

checked for performance against the Canadian Weight and Measures Act, Chapter 36, and for meeting standards within NBSH 44-H-112.

The remaining three were of the same type, and were used to weigh the boiler/economizer ash, the precipitator ash, and the refuse samples.

These weigh scales had a range of scale error within 0.25 percent for the range of loads weighed. The scale was calibrated prior to and after the test in accordance with ASME performance test code PTC 19.10 .

5.9.2   Manual Sampling Trains

The major calibration procedures used are described below:

- Pitot tubes attached to the probes had been calibrated using the procedures described in the Environment Canada publication EPS 1-AP-74-1. The probes were completely assembled during calibration, including attachment of the thermocouple and various sampling nozzles expected to be used in the field. The Atmospheric Environment Service (AES) in Toronto and Laval University wind tunnel facilities were used;

- The particle sizing probes had been calibrated in the same manner as the particulate sampling probes, with the cyclone assembly being attached before calibration;

- A Warren E. Collins primary standard spirometer and a calibrated wet test meter were used to calibrate the dry gas meters of the sampling train console, using procedures specified in the Environment Canada publication EPS 1-AP-74-1.

- Calipers were used to verify the dimensions of the nozzles; prior to each test the nozzles were checked for damage;

- The thermistors and thermocouples were calibrated against mercury-in-glass thermometers by immersion in liquids heated to the approximate working range. All thermistor readings were within 1% of the thermometer readings.

5.9.3   Process Control Instrumentation

All process control instrumentation was calibrated two months prior to the test phase by an independent contractor supervised by Roche/Lavalin and Bailey personnel.

The calibration report was submitted by the independent contractor to Roche/Lavalin. This report is available upon request to the CUQ.

5.9.4   Continuous Gases

5.9.4.1 Analyzers

The various analyzers were tested prior to their use on site to ensure satisfactory performance.

The following parameters were determined for the gaseous analyzers in a controlled laboratory environment:

- Reproducibility;
- Drifts (zero and span);
- Linearity; and
- Speed of response.

The following four sections describe the presurvey instrument tests and the results.

Reproducibility

Reproducibility is a measure of an analyzer's response to the repeated injection of a fixed gas concentration over a short period of time. This parameter was obtained for each analyzer by injecting calibration gas ten times over a short period of time (less than 5 minutes), each injection being followed by a flow of zero gas. The instrument response to each gas injection was noted. The coefficient of variation was determined from the standard deviation and mean for each data set and reported in Table 5.8.

All instruments yielded acceptable reproducibility results.

Zero/Span Drifts

Over time, the output of an analyzer may drift from the desired zero and span settings. Zero and span drifts were determined over a six-hour period by alternately injecting zero and span gas to each analyzer. The difference between the initial response and that indicated by the analyzer was considered drift. The values reported in Table 5.8 were the maximum deviations that occurred during the test period, regardless of the shape of the drift curve over the time interval.

The data indicated satisfactory zero drift performance for all analyzers. This was also true for span drifts with the exception of the TECO Model 15 HCl analyzer. As a consequence of this and of unacceptable linearity test results, the HCl unit was returned to the manufacturer for remedial work. The equipment was recalibrated in the field on the first day of the Characterization Test run.

TABLE 5.8 - RESULTS OF ANALYZER TESTING

Gas	Instrument #		Range *	Reproducibility %(SD/FS)	Drifts		Linearity	Speed of Response sec.**
					Zero %FS	Span %FS		
SO_2	WRD-721	(M)	0-250	< 1.0	1.0	< 1.0	1.3	9
NO_x	TECO 10AR	(M)	0-250	< 1.0	< 1.0	< 1.0	< 1.0	4
HCl	TECO 15	(M)	0-1000	< 1.0	< 1.0	4.1	2.2	-
CO	Bendix 8501	(M)	0-250	< 1.0	< 1.0	< 1.0	< 1.0	13
CO_2	Beckman 765	(M)	0-20%	< 1.0	< 1.0	< 1.0	2.0	-
THC(h)	Horiba	(M)	0-30	< 1.0	< 1.0	< 1.0	< 1.0	7
THC(c)	Beckman 400	(M)	0-20	< 1.0	1.3	< 1.0	2.0	-
O_2	Beckman 755	(M)	0-25%	< 1.0	< 1.0	< 1.0	< 1.0	-

* ppm unless otherwise indicated
** 0-90% change, includes lag time

(M) indicates main analyzer
FS - Full Scale
SD - Standard Deviation

Linearity

Ideally, the response of a detector is linear to the inlet concentration of the gas being measured. Many detectors provide a non-linear response to the gas concentration, thus their outputs must be modified, either by a microprocessor or by other electronic means to yield linear outputs. The accuracy of this conversion must be measured to ensure that the instrument output reflects the actual gas concentration.

The linearity was checked over the anticipated operating range of each instrument by injecting ten known gas concentrations generated with a dynamic blending apparatus. The gas concentrations were spaced equally from zero up to the concentration of the span gas used. The true concentrations and the instrument responses were noted and a response curve drawn. The data in Table 5.8 were maximum deviations from linearity observed during a test sequence, as taken from the response curve.

The linearity of each device was deemed satisfactory, with the exception of the TECO model 15 HCl analyzer. A previous test for drifts had also indicated an instrument problem which required remedial work by the manufacturer.

Speed of Response

The response time of an analyzer is the time interval from the initial injection of a gas at the analyzer inlet until a defined fraction of the gas concentration (e.g. 90%) is indicated.

Due to time constraints, the determination of this parameter was limited to selected instruments, the results of which are presented in Table 5.8. The response times ranged from 4 to 13 seconds, with most values below 10 seconds.

5.9.4.2 Verification of Gas Cylinder Analyses

The following section describes the procedures used to verify the cylinder gas concentrations and summarizes the resulting data.

One gas cylinder in each grouping was designated as a reference and the manufacturer's analysis was verified using the best available procedure. The verification procedures included comparison of reference gases against NBS gases and analyses by Standard Reference Methods. In the former procedure used to check CO and methane standards, a continuous analyzer was calibrated using NBS gas under carefully controlled conditions, followed by reference cylinder gas. The indicated concentration of the reference gas was then compared to that provided by the supplier.

Applicable Environment Canada Standard Reference Methods were used to verify the concentrations in SO_2 and NO_x cylinders. These cylinders were used to calibrate SO_2 and NO_x analyzers under

carefully controlled conditions. The concentration of the reference cylinder gases were then determined by injecting the gases into the appropriate analyzer.

In the case of HCl, the concentration in each cylinder was checked directly using procedures described in the draft HCl Standard Reference Method. Table 5.9 summarizes the concentration data generated for all reference cylinders checked during this test series.

Cylinders in a series were cross-calibrated to further check the supplier's concentrations. An analyzer was calibrated under carefully controlled conditions using the reference cylinder gas, followed by analyses of the remaining cylinders in the series. The concentrations determined for the remaining cylinders were then compared to those provided by the supplier. This comparison data is presented in Table 5.9.

Generally the concentration data showed good agreement between the supplier and the verification tests, however some anomalies were found in the CO and HCl cylinder concentrations.

There was a 6.5% difference between the supplier's analysis and that of Environment Canada for the CO reference cylinder. As a result of this disagreement, an additional cylinder (YR5948) was checked using NBS reference gas. The CO concentration thus determined (150 ppm) agreed closely with that of the supplier (152 ppm) and with a previous check in 1985 (154 ppm) against NBS reference gas. The cross-calibration concentration for CO cylinder AP8248 (200 ppm) using YR5948 as a reference gas also verified the concentration in AP8248 (199 ppm) cylinder from the NBS procedure. Thus, the supplier's analyses for cylinders AP8248 and AP8249 were deemed inaccurate, and the concentrations determined by Environment Canada were used.

All HCl gas standard cylinders were analyzed by passing approximately 30 litres of each gas through a sampling train with impingers containing water. The chloride content in the impinger catches were analyzed by ion chromatograph. The wet chemical method and cross-calibration data agreed favourably but differed significantly from the supplier's concentration for two cylinders. Thus, the concentrations determined by Environment Canada were used.

5.10 LEACHATE TEST SAMPLING

As described in Sections 5.2.2 and 5.4, separate refuse and ash samples were taken for leachate analysis. Representative samples were taken for each Performance Test mode of operation (ie. PT-02, -04, -05, -07, -09, and -14) and sent to Environment Canada's Wastewater Technology Centre, for leachate analysis. These samples were then sent to Environment Canada's River Road Laboratory (EC-RRL) for metals and organics analyses.

TABLE 5.9 - RESULTS OF CALIBRATION GAS VERIFICATION TESTS

Gas	Cylinder	Concentrations**				Comments
		Supplier Calib.	Cross-	SRM	Other	
SO_2	AP8245	230	*	-	233	Reference tank checked against cylinder analyzed by SRM
	AP8246	228	228	-	-	
	AP8247	229	229	-	-	
NO	AP8197	214	*	-	217	Reference tank checked against cylinder analyzed by SRM
	AP8198	214	210	-	-	
	AP8199	482	474	-	-	
	AP8200	482	473	-	-	
CO	AP8248	213	200	-	199	AP8248 and YR5948 checked against NBS standard by Ambient Monitoring Section (Environment Canada)
	AP8249	213	201	-	-	
	YR5948	152	*	-	150(1986) 154(1985)	
CH_4	AP8250	15.2	*	-	16.0	Reference checked against NBS standard by Ambient Monitoring Section (Environment Canada)
	AP8251	15.4	15.6	-	-	
	AP8252	15.2	15.1	-	-	
C_3H_8	YR5386	5.14	5.06	-	-	Same as CH_4
HCl	YR6156	920	*	936	-	All HCl tanks analyzed by draft SRM
	YR6157	871	799	863	-	
	YR5494	902	776	759	-	
	YR5495	925	806	803	-	
CO_2	AP8201	18.3%	*	-	-	
	AP8202	18.3%	18.3%	-	-	
O_2	AP8201	22.4%	*	-	22.8%	Ambient Air used as reference gas for O_2
	AP8202	22.8%	22.8%	-	22.8%	

* Denotes reference cylinder   ** ppm unless otherwise indicated

6.0 LABORATORY METHODOLOGY

This chapter presents the sample handling, recovery, preparation and analytical procedures followed for the various samples collected during the testing program. Table 6.1 lists, by component, the total number of individual samples which resulted from the sampling program.

Recognized analytical methodologies were followed and are detailed in Volume III. A summary of the analytical methodologies and any variations from the standard approaches is also contained in this chapter.

6.1 SAMPLE HANDLING

Each sample obtained from the field was suitably labelled with all information necessary for sample identification and interpretation of results. This section details the handling procedures carried out after sample collection, up to the analytical sample preparation and analysis procedures.

6.1.1 Field Procedure

A carefully organized approach to sample handling procedures was required for a number of reasons:

- a great variety of samples would be generated from the field program,
- samples would be ready for collection or processing at different times of the day, and
- it would be necessary to preserve sample integrity.

A sufficient number of the various sample containers were on hand in the field to last the duration of the sampling program. Unique labels were prepared in advance, typically the day before or the morning of the test, and were distributed to the various sample recovery personnel. Meetings were held with sampling personnel before the start of a test to discuss any variations from routine sample collection such as additional samples for QA/QC. To check that all required samples had been collected on any given day, all samples were inventoried the following morning of a test run, and compared with the master list.

The sample coding, tracking, storage and routing procedures followed are described in the following sub-sections.

TABLE 6.1

PERFORMANCE TEST SAMPLE ANALYSIS SUMMARY

Component	Combustible	Proximate Ultimate HHV	Particulate Concentration	Particle Size	Metals	Mercury	Acid Gas	Organics*	Moisture
Refuse		20			20			20	86
Exhaust Gas			28	126	56	42	14	111	42
Blanks				22	20	10	5	44	
Ash - Incinerator	14				14	14		14	14
Ash - Boiler	14				14	14		14	14
Ash - Precipitator	14				14	14		14	14
Ash - Quench Tank	16								16
Proofing					14	14	14	33	
Total	58	20	28	148	152	108	33	250	186

* Combined: PCDD, PCDF, CP, CB, PAH and PCB

6.1.2   Sample Coding and Tracking

Over 1,000 field samples were taken during the six weeks of Characterization and Performance Testing. To minimize errors in sample tracking and processing, each sample was given a unique, sequentially numbered, self-adhesive label and logged on the Master Sample List. The Master Sample List consisted of a computer spreadsheet which identified all of the routine samples and blanks required for each test.

Any samples additional to the routine set of samples collected in any one test day were given special sample numbers set aside specifically as extras. This ensured that duplication of sample numbers would not occur.

Sample labels for each test were prepared from the master sample list. This provided an excellent means for controlling, tracking, and cross-checking samples generated from a test.

Each pre-gummed paper label provided the following information:

- Date when sample was taken
- Sample identification number
- Run Number
- Sample Code (see the following)
- Location of collection
- Sample description
- Sample destination
- Name of QA/QC verifier
- Sampler Name
- Comments

In addition to the unique sequential sample number, all samples were identified with a four-part code identifier (TTnn-XX-ss), where:

TT   - Sampling Period

MT - Mobilization Sample
CT - Characterization Sample
PT - Performance Sample

nn   - Test Number

XX   - Sample Origin

AB - Boiler/Economizer Ash
AI - Incinerator Ash

AP - Precipitator Ash

QT - Quench Tank Ash

GP - Refuse

PA - Particle Sizing Train

HG - Mercury Train

MP - Metals/Particulates Train

OC - Organics Train

OB - Organics Train Blanks

ss   - Composite Sample Series Number
        (example for incinerator ash:

01 - jar for organics analysis

02 - jar for metals analysis

03 - jar for storage

04 - jar for storage

05 - bucket for combined analyses)

To ensure that each sample followed the proper routing procedures to its final destination, the status and final destination of each sample was incorporated into the master sample list and up-dated weekly.

6.1.3   On-site Sample Storage

Prior to shipment, samples collected or processed on the site had to be stored in a manner that would preserve their security and integrity.

A trailer (36 m^2) was provided on site specifically for the storage of samples.

The samples that were stored (without refrigeration) on-site in the locked sample storage trailer, were:

- incinerator ash (except leachate samples);
- precipitator ash (except leachate samples);
- boiler/economizer ash (except leachate samples); and
- recovered samples and blanks from the metals/particulates, mercury, particle sizing and acid gas trains.

The samples that were kept refrigerated in the locked sample storage trailer, or packed with dry ice for short periods then refrigerated, were:

- leachate ashes,
- quench tank solids or liquid,

- recovered samples and blanks from the organic train, and
- any special samples of temporarily unknown destination.

Only refuse samples were kept frozen in a locked freezer.

6.1.4   Routing Procedures

Samples either remained on-site for the duration of the testing program and were then sent to laboratories for analysis, or were shipped out at periodic intervals during the testing program.

The samples that remained on-site for the duration of the testing program were:

- all ash samples except those for organic or leachate analysis,
- all refuse samples (kept in cold storage in Quebec City), and
- all manual sampling train samples except those for organic analysis.

All manual organic train samples were packed in large coolers surrounded by freezer packs and dry ice, and sent on a regular basis by special courier directly to Environment Canada's River Road Laboratory (EC-RRL). Leachate samples and quench tank ash and water samples were similarly sent.

At the end of the field program, samples which had not been shipped were inventoried and packed in boxes. These samples were sent to the corresponding laboratory to be processed.

All sample shipments from the site were packed in labelled coolers or boxes, accompanied by a sample submission and tracking form. This document was duplicated and a copy kept on site in case of shipment difficulties. All samples but organic samples were hand-delivered to the designated laboratories by the test personnel responsible for the measurement and analysis of that component. The processing steps for each type of sample are detailed in Sections 6.2 through to 6.5.

6.1.5   Sample Status

The status of each individual sample was documented on computer spreadsheet. The same spreadsheet was used to generate self-adhesive sample labels prior to each test. As each sample passed through the various laboratory preparation and analytical steps, the following information was monitored:

- sample number;
- run number;
- test date;

- sample code;
- sample description;
- current sample location;
- final sample destination;
- type of analysis to be performed:
- current status of sample processing; and
- additional remarks.

The sorting capability of the computer spreadsheet was used to generate packing lists by sample type and by laboratory destination. For example, all of the entries for incinerator ash samples collected during Performance Testing destined for metals analysis could be extracted from the spreadsheet and a printed list sent to the laboratory along with the samples.

As each group of samples completed a processing step, the spreadsheet was updated.

6.2   MANUAL TRAIN SAMPLE RECOVERY

At the end of each run, all manual sampling trains were brought to the laboratory trailers. The sample recovery for metals/particulates, mercury, particle size distribution and acid gas was carried out according to recognized methods and procedures. The following sections provide general information on recovery procedures, however reference should be made to Volume III, Methodology, and the appropriate appendices, for more detail.

6.2.1   Metals/Particulates

Samples from the metals/particulates train were recovered according to the procedures established prior to the sampling program. Procedures followed the standard without deviation.

Five samples were recovered, from the metals/particulates train, namely:

1)   an acetone rinse of the sampling probe and the front half of the filter holder of the train, including "brushings" (Note: Brushes were used to remove all particulate material from within the glassware and probe. To collect this portion of the sample, acetone was used to clean off the brushes, constituting the "brushings".);

2)   the filter and scrapings;

3)   contents and rinses of the back half of the filter holder and impingers 1 and 2, including connectors;

4)   contents and rinses of impingers 3 and 4; and

5)   an acid proof rinse of the entire train, except the nozzle.

All recovered samples were placed into pre-cleaned and pre-labelled containers (polypropylene bottles and glass petri dishes) that were designated to the metals/particulates train. The samples were then set aside in the sample holding area of the trailer, where liquid levels were marked and a final verification made.

6.2.2   Organics

Samples from the organic sampling train were recovered according to the specifications described in the ASME protocol, set by EC-RRL, and described in Volume III. From the first six tests, seven sets of samples and relevant blanks were recovered (i.e. six runs and one blank, totalling 63 samples). They were:

ii   nozzle, probe, front filter holder brushings and rinses;

ii)   the filter, folded in half and wrapped in proofed foil, then placed in a plastic petri dish;

iii) the frit (a porous glass fitting which supports the filter on which the sample is collected), wrapped in foil and placed in a plastic petri dish;

iv)   the back filter holder and connector, brushings and rinses;

v)   the XAD-2 resin trap and condenser;

vi)   contents of impinger 1 and its appropriate connections;

vii) contents of impingers 2 and 3, and their appropriate connections;

viii) rinses of impinger 1 and its appropriate connections;

ix)   rinses of impingers 1 and 3, and their appropriate connections.

To minimize the number of samples, EC-RRL requested that some samples be combined in the field. Consequently, for each of the remaining Performance runs (PT-07 and PT-15) the samples were:

TS1   - nozzle, probe, front filter holder brushings and rinses;
TS2   - the filter, folded in half and wrapped in proofed foil, then placed into a plastic petri dish;
TS3   - the frit, wrapped in foil and put into a plastic petri dish;
TS4   - contents and rinses of the back filter holder and impinger 1 and their appropriate connections;
TS5   - the XAD-2 resin trap and condenser, connected to the inlet and outlet stems to form a closed loop (the use of Sovirel joints facilitated this step);
TS6   - contents and rinses of impingers 2 and 3 and their appropriate connectors; and
TS7   - solvent proof rinse of the entire train.

Blank train samples were recovered in the same way. On blank train days an extra train was prepared and recovered with the appropriate quantity of material handled in the same manner as a recovered material.

All sample containers used for the organic train samples were pre-proofed, pre-labelled one-litre amber glass bottles with Teflon liners, or pre-proofed plastic petri dishes. Pre-proofed aluminum foil was used where necessary.

Immediately after sample recovery was complete, sample container lids were sealed with black electrical tape, liquid levels marked, and the labels verified. The samples were then stored overnight in a small cooler containing dry ice, within the locked sample recovery truck.

6.2.3   Particle Size/Acid Gas

Samples from the particle size/acid gas train were recovered according to procedures established prior to the testing program and described in Volume III. The recovery procedure involved recovering the particulate matter contained in the nozzle/cascade impactor (or nozzle/cyclone), and recovering the water-filled impingers from the back half of the train.

As mentioned previously in Chapter 5, a five-stage cyclone was used for the first two Performance Test runs. It was discovered that the particle loading was too light to obtain an acceptable weighable sample for this type of train. For this reason, a cascade impactor able to accommodate this particle loading was used for the remaining test runs.

Eight samples were recovered from this train when the five-stage cyclones were used (PT-01 and PT-02), namely:

1)   post sampling proofing rinse;

2-6) the contents and acetone rinses of each cyclone, their brushings, and the brushings of the connection preceding the cyclone;

7)   the back-up in-stack filter and the appropriate brushings prior to it; and

8)   the contents and rinsings of the impingers.

The cyclone contents, brushings and rinsings were placed into pre-cleaned, pre-labelled polypropylene bottles, as were the impinger contents/rinses and the proof rinse. The back-up filter was placed dirty side up in a plastic petri dish. All samples were then set aside in the sample holding area.

Twelve samples were recovered when the cascade impactor was used (PT-03 to PT-15), namely:

1)   post sampling proofing rinse;

2-9) impactor filter of each respective stage;

10)   impactor back-up filter;

11)   contents of the impingers and their rinsings; and

12)   brushings and acetone rinses of the impactor pre-cyclone.

Liquid samples were put into polypropylene bottles dedicated to this train, whereas the impactor stage filters were each wrapped in a small piece of aluminum foil and placed into small whirl-pack bags. The tare weight of each filter was marked both on the foil and on the plastic bag. All samples were then set aside in the sample holding area.

6.2.4   Mercury

Samples from the mercury train were recovered according to the procedures described in Volume III, without variation.

There were three samples recovered from this train for each test run (6 on blank train days), namely:

1)   the particulate matter contained in the nozzle probe, front filter holder including brushing and acid dichromate rinsings, and the particulate filter (deposited into the same sample bottle);

2)   the contents of all the impingers ($KMnO_4$) reduced with hydroxylamine and rinsing of the back filter holder (note: generally 2 bottles were obtained), preserved with dichromate; and

3)   an acid dichromate and water rinse of the entire train (note: generally 3 bottles were obtained).

All sample containers were one-litre amber glass bottles, pre-cleaned (as described in Volume III) and dedicated to this particular train. These samples were also taken to the sample holding area of the trailer once recovery was complete.

6.2.5   QA/QC Samples

Periodically, the EC QA/QC co-ordinator requested special samples to be collected or prepared on site, for QA/QC purposes. Generally, these were duplicate or split samples. In all cases, the type of sample containers and sample handling procedures were the same for these samples as any regular samples.

6.3   SAMPLE PREPARATION

This section provides an overview of the methods used for sample preparation and highlights particulate handling procedures for certain samples. All refuse and ash samples were preprocessed before being distributed for analysis, i.e., shredded, milled, or pulverized as required.

6.3.1   Refuse

Four or five buckets (5-gallon pails) of shredded refuse were collected per run, as described in Section 5.2.2 Refuse Sampling. The shredded refuse was put through a number of basic refuse processing steps which consisted of weighing, drying, coarse milling, and fine milling.

Each pail was processed as follows:

GP Pail #1 :   air dried at 40°C then milled and processed for organic and inorganic analyses
GP Pail #2 :   oven dried at 105°C
GP Pail #3 :   retained in cold storage then air dried at 40°C for moisture content
GP Pail #4 :   retained in cold storage then air dried at 40°C for moisture content
GP Pail #5 :   processed for leachate analysis.

Milling of the refuse samples was carried out by the Ontario Centre for Resource Recovery (OCRR) in Downsview, Ontario. The air-dried series GP Pail #1 was processed one run at a time. (The oven-dried series GP Pail #2 was not processed, in order to minimize the potential loss of organic and inorganic, i.e. selenium, mercury, compounds at elevated temperatures.) For each run, the following procedures were carried out:

1)   The buckets of refuse were weighed as received. The contents of each bucket were spread out on a clean surface and rejects (such as ferrous and non-ferrous components, glass and ceramics) were removed, weighed, and archived. The ferrous components were extracted with the help of a magnet.

2)   The remaining sample was milled in a blade-type milling machine using the coarse grid attachment, and then riffled down to about 300 grams of refuse. A riffling machine separates a sample into two homogeneous sub-samples. Each subsequent smaller sub-sample is passed through the riffling machine until the desired sample size is achieved. The sub-sample was then milled using the fine grid attachment. Dry ice pellets were used to cool the milling machines thus minimizing the loss of organic compounds, and to freeze rubber and plastic material before milling. The freezing allowed material to be more finely divided, thus ensuring more homogeneous samples for analysis.

For each run, four jars were filled with about 50 grams each of the sample, and distributed as follows:

GP-06 :   was sent to Environment Canada's River Road Laboratory (EC-RRL) for organics analyses;
GP-07 :   was sent to the Ontario Research Foundation (ORF) for metals analyses;
GP-08 :   was sent to Diagnostic Research Laboratories (DRL) for ultimate, proximate and combustibles analyses; and
GP-09 :   was retained by Lavalin for temporary storage.

Quality control selected two test runs, PT-02 and PT-04, from which four extra jars per run were filled with about 50 grams each of finely milled sample, and sent out for analysis.

For 6 Performance Test runs (PT-02, -04, -05, -07, -09, -14), the five-gallon pail of series GP Pail #5 samples were sorted, shredded, riffled and milled as per the series GP Pail #1. The entire pail of

shredded sample was sent to the Environment Canada Wastewater Technology Centre (EC-WTC) for leachate analyses, along with 50 grams of finely milled sample.

6.3.2   Incinerator Ash

The incinerator ash sampling procedure carried out during the Quebec City test was somewhat different than that of the PEI test. The change is sampling procedure was primarily due to the composition and amount of ash collected. A larger quantity of ash was collected and handled during the Quebec City test. The composition also varied from PEI incinerator ash, in that the Quebec City ash contained unburnt and non-combustible material (i.e. clumps of moist sod, strips of metal, and large chunks of clinkers).

The ash was sampled by inserting a large shovel into the incinerator, removing material from the grate and placing it into 5 gallon buckets.

Large items such as steel plates, water heater tanks, pipes, etc. that commonly move down the grates, obviously could not be sampled.

For the Performance testing, fourteen five-gallon pails of incinerator ash in total were processed. The basic processing steps included weighing, sorting, crushing and milling of the ash.

The manual sorting procedure extracted all substances which were larger than the mouth of the crusher, or unsuitable for passage through the crusher, such as ferrous and non-ferrous metals, glass, ceramics and sod. The rejects were classified into either metals or non-metals, weighed and then archived in their respective pails.

The remaining sample was passed through a 6-pound jaw crusher and crushed to approximately quarter-inch size. The crushed ash was then coned and riffled, and milled in a cold steel mill to a fine powder, about 50 to 100 mesh.

Dry ice was not used during the crushing and milling process because it was ascertained that the heat generated would not exceed 40°C.

For each run, approximately 50 grams of milled powder was put into four jars, as follows:

AI-01 :   sent to Environment Canada's River Road Laboratory, for organics analysis;
AI-02 :   sent to Ontario Research Foundation for metals analysis;
AI-03 :   retained by Diagnostic Research Laboratories for analysis of combustibles; and
AI-04 :   sent to Lavalin for temporary storage.

For runs PT-04 and PT-07, four extra jars per run were filled with about 50 grams each of finely milled sample, and sent out for quality control (EC QA/QC) analysis.

Six pails of incinerator ash were processed for leachate analysis. The processing steps included sorting and crushing as described in Section 6.3.2, but no milling.

6.3.3   Boiler/Economizer Ash

Although the boiler/economizer ash was much more homogeneous than the incinerator ash, there were still chunks of carbon and flakes of ash which necessitated milling.

Four jars of boiler/economizer ash per run (56 in total) were processed. To minimize cross-contamination between runs, all four jars of ash per run were put through the pulverizer in a specific order. Storage jar AB-03 contents were put through first, followed by the contents of storage jar AB-04, metals jar AB-02 and organics jar AB-01, respectively. Quality control samples were milled after the organics sample, (when required). The contents of each jar of ash were returned to the same jar after milling. The milling machine was brushed down and vacuumed between each run. Dry ice was put through the milling machine periodically to minimize loss of organic compounds.

After milling, the jars were distributed as follows:

AB-01 :   sent to the Environment Canada River Road laboratory for organics analyses;
AB-02 :   was sent to the Ontario Research Foundation for metals analyses;
AB-03 :   was sent to Diagnostic Research Laboratories for combustibles analyses; and
AB-04 :   was retained by Lavalin for temporary storage.

In addition, 30 jars of boiler/economizer ash samples which were requested by the EC QA/QC were taken for quality control purposes to be analyzed by an independent laboratory.

6.3.4   Precipitator Ash

The precipitator ash was already in an acceptably homogeneous state, however it was decided to mill the samples following the same procedures as the boiler/economizer ash, to ensure sample consistency.

Four jars per run (56 jars in total) of precipitator ash were processed. After milling, the jars were distributed as follows:

AP-01 :   sent to the Environment Canada River Road laboratory for organics analyses;
AP-02 :   was sent to the Ontario Research Foundation for metals analyses;
AP-03 :   was sent to Diagnostic Research Laboratories for combustibles analyses; and
AP-04 :   was retained by Lavalin for temporary storage.

6.3.5   Quench Tank Ash

In total, for the Performance testing, fourteen jars and two five-gallon pails of quench tank ash were taken. The jars of ash were dried at 105°C and the moisture content was determined, as per section 6.4.8. The ash samples were then analyzed for combustibles. No attempt was made to handle the oversized components of the ash.

The two five-gallon pails of quench tank ash were dried. The pail contents were subsequently sorted, crushed, milled and analyzed for combustibles.

6.3.6   Leachate Ash and Refuse

Twelve pails of refuse and incinerator ash were processed for leachate analysis from the following Performance Test runs: PT-02, -04, -05, -07, -09, -14. The processing steps included sorting and crushing as described in Sections 6.3.1 and 6.3.2, but no milling.

6.4   ANALYTICAL PROTOCOLS

Sample analysis was undertaken by laboratories conversant with the methodologies required. Dioxin, furan, PCB, PAH, CP and CB analyses were completed by the EPS Analytical Services Division (ASD). Diagnostic Research Laboratories completed the ultimate, proximate, HHV, and combustibles analyses. Ontario Research Foundation completed the metals analysis. In most cases, standard methods were applied; details are presented in Volume III and summarized in the following section.

6.4.1   Metals

Samples for metals analysis were prepared in a manner compatible with the nature of the sample and the analysis required. The preparation procedures included "digesting" the samples with aqua regia followed by a concentration process and subsequently analysis.

Trace metals (Al, Ag, Ba, Be, Bi, B, Cd, Ca, Cr, Co, Cu, Sn, Fe, Mg, Mn, Hg, Mo, Ni, P, Pb, K, Si, Na, Ti, V, Zn), for the most part, were analyzed by Direct Current Plasma (DCP). This technique provides a sensitivity as good as atomic absorption for most metals, with the added benefit of reduced sample handling and analytical cost, since many compounds are analyzed at the same time.

Atomic absorption was the preferred method for analysis of Arsenic (As), Antimony (Sb), Selenium (Se) and Tellurium (Te), because of its ability to provide the increased sensitivity necessary for analysis for these metals.

6.4.2   Organics

One of the objectives of the Quebec combustion emission testing was to monitor feed, ash and exhaust gas emission levels of six classes of organic compounds under a variety of operating conditions. The following classes of compounds were targeted for analysis: polychlorinated dibenzo-p-dioxins and polychlorinated dibenzo-p-furans (PCDD/PCDF), polychlorinated biphenyls (PCB), chlorinated benzenes (CB), chlorinated phenols (CP), and polycyclicaromatic hydrocarbons (PAH).

The fundamental steps in the processing and analysis of all organic samples consisted of:

1)   Solvent extraction of organic contaminants from the sample matrix.

2)   Cleanup of the raw extract to remove some of the co-extracted non-target organics, and to separate target organics into four fractions for class-specific analysis.

3)   Instrumental analysis of each fraction.

4)   Data interpretation and quantitation of target organic levels.

Laboratory procedures for the extraction, cleanup and GC/MS analysis of the various types of samples received are schematically illustrated in Figure 6.1 and summarized as follows.

1)   Extraction

All solid samples (ash, train particulate, XAD resin and refuse) were extracted with benzene for 20 hours in a soxhlet apparatus. Prior to extraction, particulate and ash samples were treated with 1N HCl to dissolve inorganics and increase the surface area available for extraction. All non-solvent liquid samples (leachate, combined condensate/glycol, filtrate from acid treatment) were extracted by shaking with three portions of an organic solvent in a separatory funnel. Concentrations of train glassware rinse samples, raw extracts, and extract fractions were determined by rotary evaporation under reduced pressure.

Because of the poor recoveries of dioxin surrogates on some boiler and precipitator ash samples, a second aliquot of these ash samples was re-analyzed for PCDD/PCDF using a modified extraction procedure. Ash samples were treated with either 3N HCl or 6N HCl instead of 1N HCl and some HCl treated ashes were subjected to ultrasonic extraction in benzene for one hour prior to soxhlet extraction.

Train component samples were combined during the extraction phase, as indicated in the schematic, so as to yield 3 raw extracts for cleanup and analysis. One extract represents the combined front half

fig   6.1

to be provided by Environment
Canada

components of the sampling train (cyclone contents and train filter), while the second represents the organics found in Amberlite XAD-2 resin trap. The third extract represents organics found downstream of the amberlite trap and allows for assessment of the collection efficiency of the sampling train.

2) Cleanup

Concentrated raw extracts were split into two equal volume portions prior to cleanup. All refuse raw extracts except the PAH fraction were subjected to an additional step of washing with a concentrate of sulfuric acid (3 x 50 mL) to remove interfering co-extractants prior to the normal cleanup described below.

The two portions of raw extract were subject to different cleanup procedures, each cleanup yielding two fractions for analysis. One portion of the extract was passed through a series of three columns. Easily-oxidized organic species were removed by the first column, which contained sulfuric acid-coated silica gel. Sulfur was removed by the second column, which consisted of silver nitrate-treated silica gel. The final column, activated basic alumina, was eluted with two solvent mixtures of differing polarity to separate chlorobenzenes and PCB's from PCDD/PCDF. The CB/PCB fraction was concentrated to a final volume of 1.0 mL for GC/MS analysis. The final volume of the PCDD/PCDF fraction was determined on the basis of the GC screening results, but was typically 100 uL.

The second portion of the split extract was back-extracted with 3 portions of an aqueous solution of potassium carbonate. The aqueous and solvent phases, containing chlorophenols and PAH respectively, were individually processed from this point on. Acetic anhydride was added to the aqueous phase to convert sample chlorophenols into acetyl derivatives. Derivatized chlorophenols were extracted back into solvent, which was concentrated to a final volume of 1.0 mL for analysis. The solvent phase from the back-extraction was concentrated, subjected to a silica gel column cleanup if necessary, and analyzed for PAH at a final volume of 1.0 mL.

3) GC/MS Analysis

All four fractions of each sample were analyzed by gas chromatography/mass spectrometry (GC/MS). To achieve the lowest possible detection limits, only selected ions characteristic of individual target compounds, or homologous groups of target compounds, were monitored. Final interpretation of all GC/MS data was performed manually to screen out any data which did not satisfy all of the established criteria for target compound identification.

Prior to extraction, train filters, XAD resins, impinger contents, ash and refuse samples were spiked with known amounts of isotopically-labelled surrogates representing the various target classes. Surrogate recovery values provide a measure of the percentage loss of target compounds during sample processing (extraction, concentration and cleanup) and for the dioxin and furan analysis, are used to correct sample data for such losses.

A performance standard, d10-fluoranthene or d12-triphenylene, was added to each final extract at a known concentration just prior to GC/MS analysis. This allows for monitoring of instrument and operator performance variables to ensure stability of instrument response and reproducibility of the sample injection volume.

The linear calibration range for each class of compounds was established by running multi-level calibration standards on GC/MS prior to the initial data of sample analysis. The retention time windows for PCDD/PCDF were monitored by analysis of a column performance check mixture which contains the earliest and latest eluting isomers within each homologous group of PCDD/PCDF. Quantitation of target analysis in samples was based upon results for a single point calibration with an external standard mixture. On a daily basis, a minimum of two calibration runs, one at the beginning and one at the end of each batch of analysis, were performed. Samples analyzed on a given data were quantitated against calibration standard responses for the same data.

6.4.3   Particulate Loading and Particle Size Distribution

Particulate loading was determined using the filter and probe residue weights from the metals train.

The filter weight was determined gravimetrically, as specified in EPS method, 1-AP-74-1.

Analysis of the blanks from the particulate train probe revealed a very high particulate concentration, often higher than the collected particulate samples from the stack sampling rain. It is suspected that the pure acetone used to rinse the probe, had dissolved some part of the plastic bottle in which the washings were stored, over the one-month period between collection and laboratory analysis. Thus the results for the total particulates concentration could not be used. It was then necessary to back-calculate a final concentrations for particulates from the metals analysis.

Since the metals and particulates trains were combined, the ratio of the metals concentration to the particulates concentration on the filter, was assumed to be the same for the probe rinses. The probe residue weight was calculated from the corresponding metal oxide and chloride from the metals analysis and the ratio of metals and organic matter on the filter.

Particle size distribution was determined gravimetrically by weighing each stage using the method stipulated in the EPS method 1-AP-74-1. A copy of this method is provided in Volume III.

6.4.4   Chloride

Chlorine analysis was conducted by Ion Chromatography as detailed in Volume III, "Chlorine Analytical Method".

6.4.5   Mercury

Mercury analysis was conducted on an atomic absorption spectrophotometer with a hollow mercury cathode lamp by the flameless cold vapour technique using a 20 cm glass flow-through cell, as specified by Environment Canada and described in detail in Volume III, "Mercury Analytical Method".

6.4.6   Calorific Value

The higher heating value (HHV) or gross calorific value was determined on the combustible fraction of the refuse samples using an oxygen bomb calorimeter. Using this instrument, a measured sample, usually 0.75 gram, is ignited by an electrical wire in an atmosphere of pure oxygen. The sample's heat of combustion warms a water bath surrounding the bomb, thus the temperature rise is proportional to the heat of combustion and the heating value can be calculated. Analyses of calorific value followed the procedure described in ASTM D2015. Fractions removed prior to HHV determination, included oversize material, metals, glass, and the like.

6.4.7   Combustibles

Combustibles or loss on ignition was determined on one sample per run of quench tank, incinerator, boiler/economizer and precipitator ash. Quench tank ash excluded oversize material present in the ash.

Each sample was dried, weighed and placed in a crucible. The open crucible was heated in a muffle furnace to 750°C until constant weight was reached. The weight loss was reported as the percent loss on ignition.

Analyses of combustibles followed the procedure as described in ASTM D3174-82.

6.4.8   Moisture

Moisture was determined for the refuse samples and the quench tank ash samples. Refuse samples were weighed as received and their contents spread out on individual trays and dried to a constant weight 40°C for GP 1, 3, 4 and 5 and 105°C for GP 2.

Quench tank samples were weighed in their containers as received; the contents were spread out on individual aluminum trays and then dried overnight at 110°C.

This procedure for determining moisture follows the ASTM method E790. Percent moisture is calculated as the quotient of the water vapour evaporated during the drying process, and the weight of the moist sample as received.

6.4.9   Ultimate/Proximate

Proximate analysis is the determination, by prescribed methods, of moisture, volatile matter, fixed carbon (by difference), and ash. Unless otherwise specified, the term proximate analysis does not include determinations of chemical elements or any determinations other than those named.

Ultimate analysis refers to the determination of carbon, hydrogen, sulfur, nitrogen, chlorine, ash, and oxygen in a dry sample. The percentage of oxygen was obtained by calculating the difference between 100% and the other determined elemental analyses.

The ultimate analysis is required in order to determine the products of combustion of a material, its combustion air requirements, and the nature of the off-gas or combustion products.

Ultimate and proximate analysis procedures are defined by the American Society for Testing and Materials (ASTM) (refer to Table 6.2). These ASTM methods were followed rigorously by the Diagnostic Research Laboratory with the following exceptions:

- Instead of using the ASTM standard method for carbon and hydrogen, the standard Leco furnace technique was used because, in addition to determining carbon and hydrogen, the Leco furnace technique determines nitrogen. Nitrogen was also determined using the ASTM Kjeldahl method. This provided a nitrogen check.

- For chlorine, argentometric titration using silver nitrate was used, in place of Volhard titration. Both methods are acceptable, but the former preferred by the laboratory.

- Turbidometric methods were used in the determination of sulphur, instead of gravimetric methods. A National Bureau of Standards coal sample was analyzed using both methods, and results were found to be comparable. The turbidometric method was preferred due to its speed and ease of analysis.

6.5   LEACHATE TEST SAMPLING

A modified Multiple Sequential Batch Leaching Procedure was employed to evaluate the mobility of organic contaminants. This procedure is documented in the EPS report, entitled "Development and Applications of a Multiple-batch Leaching Procedure", provided in Volume III. A distilled water leach, at a 20:1 liquid-to-solid ratio, was performed and repeated at higher ratios.

Table 6.2
Standard ASTM Methods for Ultimate/Proximate

Parameter	ASTM Reference	Exception
Ash	D3174	-
Volatile Matter	D3175	-
Carbon, Hydrogen	D3178	Leco furnace technique
Nitrogen	D3179	Determined by two methods
Chlorine	D2361	Argentometric titration
Sulfur	D3177	Turbidometric technique
Higher Heating Value (Gross Calorific Value)	D2015-77	-

Briefly, the procedure involves placing a 45 gram sample of ash and 900 mL of distilled water in a glass jar and rotating the container for 18 hours at a speed of 2-3 rpm. The leachate samples were allowed to settle for 30 minutes before decanting the supernatant and filtering it through Whatman #4 qualitative filter paper. The leachate samples and the leached ash samples were shipped to River Road Laboratories for organics analyses.

The regulatory leach test procedures set out in the Government of Ontario Regulation 309 were strictly followed to classify the ashes as either hazardous or non-hazardous wastes.

The Multiple Sequential Batch Leaching Procedure was used to determine the mobility of heavy metals in the ash over a period of time, under non-aggressive leaching conditions. This method is currently undergoing standardization tests by ASTM. The method involves using a distilled water batch leach test at a 20:1 liquid-to-solid ratio, similar to the one listed above. However, instead of allowing the sample to settle, the slurry is poured into a pressure filter and percolated through a 0.45 micron membrane filter. The filter was measured for pH, conductivity and total dissolved solids before being analyzed for heavy metals. The leached ash was then placed back in the leaching container where it was exposed to fresh leaching media at a 20:1 liquid-to-solid ratio. This was carried out for five cycles. Volume III contains a detailed description of the procedure.

The ashes were also subjected to the Sequential Chemical Extraction procedure. This procedure was initially developed to estimate metal speciation in sediments, but has been adapted for ashes. The procedure was used to determine short- and long-term leachability estimates for the metals present in the ashes. This procedure is detailed in Volume III, "Availability of Elements of Environmental Importance in Incinerated Sludge Ash".

The acid neutralization capacity of each ash was determined using the ASTM procedure C400-64, with the exception that a solution of 0.5 N (normal) nitric acid (HNO_3) was used instead of a 0.3 N sulphuric (H_2SO_4) solution. The nitric acid solution was preferred because of the small amount of buffering capacity required. Because HNO_3 has only one hydrogen ion while H_2SO_4 has two, the former was considered to produce more accurate results. All the ashes were ground to pass through a #100 mesh sieve prior to testing in order to obtain a more accurate indication of their buffering capacities.

The heavy metal concentrations in both the ash and the leachates were measured by inductively coupled argon plasma, flame atomic absorption or graphite furnace flame atomic absorption.

Details of the results of the leachate tests can be found in a separate report issued by Environment Canada.

7.0   QUALITY CONTROL PROCEDURES

7.1   OVERVIEW

Due to the broad program scope and the number of parties involved in the project team, considerable effort was made to blend the activities of all parties together to ensure a high level of quality control.

Lavalin established its own Quality Assurance/Quality Control (QA/QC) program in parallel with, and to complement, Environment Canada's QA/QC program. Through their contract with Concord Scientific, the Ontario Ministry of the Environment (MOE) assumed the overall QA/QC responsibility for Environment Canada.

In general, the QA/QC personnel were responsible for overseeing all sampling and analytical aspects of the test program, to ensure the sample quality. Briefly, the duties of the QA/QC involve:

- ensuring compliance with standard EPS/NITEP test methods through:

     - a thorough understanding of all methods on the part of the respective operators and sample handlers, and
     - adherence to recommended equipment procedures and their corresponding calibration;

- verifying that all equipment is functional, proofed, and calibrated;

- ensuring that all test personnel understand the procedures that they are to follow, and subsequently regularly verify during the test that the procedures are followed correctly;

- ensuring sample integrity for analysis throughout collection, recovery, and transfer;

- ensuring the quality of the data collected through the data acquisition and after processing;

- collecting duplicate samples for the various test processes, for independent analysis; and

- verifying laboratory procedure for organic and inorganic analysis.

7.2   LEVEL OF RESPONSIBILITY

The overall QA/QC contractor was not chosen until the start of the Performance testing phase. The Ontario Ministry of the Environment (MOE) assumed this position during the Mobilization and

Characterization phases. The overall QA/QC contractor reported to the MOE. As a consequence of this arrangement, general areas of responsibilities were delineated between the Lavalin QA/QC and EC QA/QC (provided by the MOE). This was instituted to prevent duplication of effort but moreover, was intended to cover all aspects of the QA/QC program.

The structure for the QA/QC program is as follows:

i)   Lavalin and the MOE both reported to Environment Canada. Lavalin hired an independent QA/QC while Concord Scientific provided QA/QC for the MOE (herein known as the "EC QA/QC").

ii) Lavalin's QA/QC oversaw the pre-test or Mobilization phase in collaboration with the MOE.

iii) Again, Lavalin's QA/QC oversaw the Characterization testing phase in collaboration with the MOE.

iv) During the Performance Test, both (Lavalin and Concord Scientific) QA/QC personnel oversaw different aspects of the program.

v)   QA/QC for the laboratory analytical procedures involved EC QA/QC personnel, reporting to the MOE, specifying procedures to be followed for analysis of each component.

7.3   FIELD QUALITY CONTROL

The QA/QC tasks are discussed in this subsection for the following three phases:

1)   the Mobilization phase,

2)   the testing phase (both Characterization and Performance Tests), and

3)   the post-testing phase.

7.3.1   Mobilization Phase

The principal QA/QC tasks during the mobilization phase were to ensure the adequacy of equipment, supplies, procedures, and data sheets or forms to be used in the field. The QA/QC activities in this phase, and the manner in which they were addressed were as follows.

Sampling Procedures

Other than the ash and refuse sampling procedures, most sampling procedures involved published standard methods or those used on past NITEP programs. Therefore the main activity here was to ensure that ash and refuse sampling procedures were prepared and reviewed prior to their use, and to ensure that sampling crews were intimately familiar with the methods to be used. For the stack sampling crews, familiarity with the standard methods was required. This involved the stack sampling procedures for the metals/particulates, organic, mercury, and particle sizing/acid gas trains. All crews

were trained prior to going into the field, tested during the Mobilization phase and Characterization Test and closely monitored throughout the Performance Test runs. The same team leaders were used throughout the project. However, more people were required to participate in the Performance Test runs.

Equipment Calibration

All equipment was calibrated by standard procedures prior to their use in the field. The calibration procedures were discussed with and approved by the SA and EC QA/QC.

Within this broad category, QA/QC concerns were expressed for:

- the load cell and weigh scale calibration,
- the manual stack sampling equipment calibration,
- the datalogger calibration,
- the Bailey process control equipment calibration, and
- the continuous monitors and span gas calibration.

In accordance with standard procedures, the Toledo Scale was installed; the load cells used to weigh the bucket loads of refuse being charged to the incinerator were checked. A letter of certification is appended in Volume III.

The weigh scales used to weigh drums of ash and refuse rejects, etc., were set up by Toledo Scale and checked against a set of weights that were left for the duration of testing.

As previously detailed in Section 5.9.2, the manual sampling trains underwent major calibration procedures as specified by the standard protocols. Briefly, the probes were completely assembled during calibration, including attachment of any thermocouples and various sampling nozzles expected to be used in the field. The pitot tubes, dry gas meters, thermistors and thermocouples were calibrated. It was ensured that readings were within acceptable ranges. Calibration sheets are included in Volume III.

The dataloggers used as part of the data acquisition system were calibrated by the supplier, Instrument Rentals of Canada, in mid-April 1986. Calibration procedures used were in accordance with the National Bureau of Standards (NBS), and National Research Council of Canada (NRCC) methods. Certificates of calibration are included in Volume III.

Calibration of the Bailey process equipment was carried out as part of the start-up and commissioning of the unit and was completed just prior to the Characterization Tests. Certificates of calibration can be made available on written request to the CUQ.

Continuous monitors utilized during the testing program were subjected to a series of laboratory tests by Environment Canada to evaluate the instrument linearity over the expected range of operation, reproducibility, response time, and zero/span drifts.

The supplier's assays of the certified calibration gases used for daily instrument calibrations were confirmed by Environment Canada using standard reference methods and/or cross calibration techniques. The results of the continuous analyzers and span gases calibrations are included in Volume V.

Data Sheets, Field Forms and QA/QC Checklists

In view of the quantity of information to be collected and the number of persons involved, field forms for manual data gathering were prepared, reviewed and approved, prior to the testing. Many of the data sheets and forms from the previous PEI NITEP program were used. These were revised as required, and several additional sheets prepared specifically for this program. Samples of all of these sheets are included in Volume IV.

Proofing of Trains, Sample Containers and Recovery Reagents

The acceptability of the sampling trains, sample containers, and sample recovery reagents for the organic, metals/particulates and mercury trains were documented prior to their use.

For the organic train, separate sets of glassware were used for each Performance Test run. Therefore proof rinses for each set were prepared prior to the field test. The proof rinses of glassware, sample containers pure blank solvents and XAD resins were sent to Zenon Environmental Inc. for analyses. The results from these analyses are included in Volume IV.

For the metals/particulates and mercury trains, several samples were prepared by Roche and submitted to ORF for analyses. These samples represented proof rinses, container rinses, filter blanks, reagent blanks, and in the case of the mercury train, an additional sample representing reduced and preserved permanganate.

The particle size distribution, mercury and metal trains were cleaned between the tests and reused during the Performance Test. However, after each cleaning, a final rinse was obtained and analyzed for trace and major metals.

Validation of the Data Acquisition System

In view of the importance and complexity of the data acquisition system and the fact that 90% of the data was processed by the computer, verification was made to ensure that:

● the dataloggers were reading correctly;

- the computer output matched what was read by the dataloggers; and
- continuous gas instrument status was properly read.

This was achieved by repeated simulation prior to the test runs.

Datalogger #1 (thermocouple datalogger) was used to verify and ensure that the thermocouple readings corresponded to the data stored and presented in the test run summary report.

The status flags of the continuous gas instruments (Datalogger #2) were verified by putting the gas analyzers through a series of steps representing off-line, on-line, zero, and calibration modes (not necessarily in this order). The result showed precise reporting of instrument status.

Thermocouple Checks

Readings observed during the start-up of the incinerator were used to flag what appeared to be either improperly connected or bad thermocouples. All thermocouples appeared to read correctly after a few adjustments were made. Just prior to the PT series, process thermocouples at the boiler inlet or at the ID fan were audited and witnessed by an MOE representative.

Computation Verification

Spot checks were performed on the data computation program. The computer program provided:

- a check on the isokinetic calculation program (done prior to CT series);
- a check on the numerical averaging, standard deviation, variance etc. produced in the datalogger measurement analysis report; and
- a check of the 15-minute averaging.

7.3.2   Testing Phase

The principal QA/QC tasks during the testing phase are outlined below.

Before testing commenced:

1)   inspection of sampling trains;
2)   inspection of sample containers;
3)   final revisions to field sheets and forms;
4)   inspection of the sample recovery trailers and storage facilities;

5) final review of ash and refuse sampling procedures;

6) final review of master sample list;

7) discussing sample recovery and protocols with sampling personnel;

8) a final review of sample disposition;

9) a discussion of the leak check criteria; and

10) finalization of the QA/QC daily routine during testing;

11) continuous monitoring system checks.

Once the PT series started, the QA/QC activities settled down to an established routine, with minor variations such as additional sample requirements. The primary responsibilities of the QA/QC were as follows:

1) witnessing all leak checks of the manual sampling trains;

2) periodical witnessing of the operation of the manual sampling trains and the equipment status;

3) witnessing the calibration of the continuous gas instrumentation;

4) witnessing sampling operations for refuse and incinerator ash, boiler/economizer ash, and precipitator ash;

5) sample recovery audits on a periodic basis;

6) review of data sheets;

7) sample handling, recording and delivery to the sample storage trailer or for shipping;

8) maintenance of the master sample list and sample submission forms;

9) ensuring QA/QC samples were collected and processed;

10) review of stack sampling data from the previous day's test;

11) preparation and distribution of sample labels; and

12) liaison with the testing supervisor, and the Scientific Authority (SA).

7.3.3   Post-testing Phase

Post-testing QA/QC was performed by the EC QA/QC and involved laboratory QA/QC activities. To quantify the analytical precision and accuracy and to assess the reliability of the analytical data, an interlaboratory QA/QC program was initiated. Laboratories participating in this comparison study included Environment Canada (organic analysis), Ontario Research Foundation (metal and mercury analysis), Environment Quebec (metal, mercury, PCB, CB, PAH and CP QA analysis) and Environment Ontario (PCDD and PCDF QA analysis).

The interlaboratory QA/QC program involved submitting split samples for replicate analyses, organic analytical sample extracts and standard reference materials to the main laboratories and QA laboratories. Both the main and QA laboratories performed the analysis using the prescribed NITEP analytical methodologies and detailed internal QA/QC protocols.

In addition to the interlaboratory analyses, a performance audit of the main laboratories was carried out by the EC QA/QC during the analysis of the project samples. The performance audits consisted of observing the sample handling, analysis and data entry/calculation procedures within the laboratories to ensure that proper procedures were followed.

7.4 LABORATORY QUALITY CONTROL

The internal Quality Assurance Program for the NITEP/Quebec study consisted of the following main elements.

Metals and Mercury Analysis

- Samples were analyzed with standard solutions run for every 5 samples by Direct Current Plasma (DCP), every 15 to 20 samples by Atomic Absorption (AA), and every 10 samples by Ion Chromatography (IC).

- Method blanks were run with each batch of samples analyzed.

- A minimum of 10% of all samples were subjected to duplicate analysis.

- A reagent blank was run between mercury samples to ensure that the analysis system had been purged of mercury. For metal analysis, reagent blanks were processed and analyzed with each batch of samples.

- Spiked control samples were run in conjunction with field samples to monitor the efficiency of the analytical method (digestion and analysis).

- NBS Coal fly ash (#1633a) was processed and analyzed along with process samples.

- A calibration curve was constructed for the analysis of mercury. Each curve contained a minimum of five points in the range of 0-200 ug. The calibrations were re-checked once the analyses were complete

- The ion chromatograph was calibrated daily (multi-point) in the concentration range of the samples being analyzed.

- Blind replicate analysis of selected ash samples, standard reference materials, and split samples provided by the EC QA/QC coordinator were analyzed.

Organic Analysis

- Prior to solvent extraction, all samples were spiked with isotopically labelled compounds (3 for PCDD/PCDF, 3 for CB/PCB, 2 for CB and 4 for PAH) to determine percent recovery on an individual sample basis (i.e. to measure overall recovery efficiency).

- Just prior to the GC/MS analysis, all samples were spiked with an internal surrogate standard to evaluate instrument/operator performance (d_{10}-Fluoranthene or d_{12}-Triphenylene).

- Control samples consisting of solvents (ethylene glycol/water - 250 mL, XAD resins - 25 g) and a filter spiked with native isomers, were processed along with field samples to monitor the efficiency of the clean-up columns.

- Method blanks (i.e., filters, resins, solvents, glassware rinse and soxhlet extraction) were also analyzed.

- Blind replicate analysis of selected ash samples and standard reference materials provided by the EC QA/QC coordinator were analyzed.

- Blank trains (3) and reagent blanks of field samples (10) were analyzed to evaluate the background level of target compounds for data correction.

7.5   INDEPENDENT QUALITY CONTROL

7.5.1   Summary

As previously described, due to both the importance of the NITEP test work and the extensive amount of sampling and data gathering, an independent third party external quality assurance/quality control (QA/QC) program, funded and administered by the Ontario Ministry of the Environment, was undertaken by Concord Scientific Corporation. The findings of both internal (Lavalin Inc.) and external QA/QC programs indicate that the field study was executed properly and according to the stated sampling and analytical protocols. The external QA/QC (EC QA/QC) contractor was on-site for the duration of the field program and monitored (in conjunction with the internal QA/QC) all sampling and on-site data collection, processing and reduction activities. In addition, the performance of the internal QA/QC (Lavalin) was audited by the external QA/QC (EC).

Samples collected during this test program were deemed to be representative and the data reported was complete and accurate. To the best of EC QA/QC knowledge, all errors, omissions and problems are correctly documented in the main reports.

The results from the interlaboratory QA/QC program indicate that both the organic and metal samples were analyzed by all laboratories within an acceptable degree of precision (metals % RSD 30%, organics % RSD 50%) and accuracy (recoveries of 70%).

The QA laboratories confirmed the results obtained by the main laboratories. Poor interlaboratory comparisons were noted however, for arsenic and barium and for chlorophenols (uncorrected for spike recovery) in the boiler and precipitator ashes. Volume V, the NITEP Quebec City Combustion QA report, describes in detail the findings of the external QA/QC.

8.0   HISTORICAL INCINERATOR EMISSIONS

8.1   OVERVIEW

It was important to review past emission testing programs carried out at the Quebec Incinerator in order to become familiar with the incinerator's performance capabilities and to avoid any problems encountered previously. One such study, undertaken by Shawinigan Engineering Ltd. in 1978, resulted in the installation of the lined waterwall arch above the drying and burning grates of each incinerator with the redistribution of the secondary air as described in Section 2. Previous studies on the Quebec Incinerator also include annual emissions stack tests which have been carried out over the last several years by the Provincial Government. In addition, parallel Hi-Vol sampling of flue gases from Unit #4 (NITEP unit) and Unit #1 was carried out by the CUQ during the NITEP sampling program to provide insight into the difference in particulate emission rates experienced between the modified unit (1986) and the 1987 design.

8.2   SUMMARY OF EMISSION TESTING PROGRAMS

8.2.1   Provincial Government Tests in 1977/78

A Provincial Government emission program was undertaken in December 1977 and May 1978 prior to the installation of the waterwall arch above the grates. During these tests, Unit #1 emissions after the electrostatic precipitator were determined. The test results are presented in Table 8.1.

8.2.2   Shawinigan Modification Effects

Scope of Work

Shawinigan Engineering, in March 1978, were commissioned to improve the combustion performance and to reduce the unburned carbon at the Quebec Incinerator. The work was undertaken in three phases as follows:

1)   Study and assess the operation of the system and make recommendations;

2)   Carry-out pilot tests to confirm recommendations; and

3)   Undertake permanent modifications to the units in accordance with the recommendations of previous phases.

TABLE 8.1

Emission Tests Results Before and After Modifications[1]

| | Tests before Arch Installation | | | | | Tests after | | |
| | December 1977 | | | May 1978 | | October 1978 | | |
	1	2	3	1	2	1	2	3
Particulate Emission Concentration (mg/Nm^3 corrected to 12% CO_2)	2253	3004	2267	1226	1089	391	232	655
HCl Emission Concentration (ppm)	1202	1179	830	-	-	469	442	426
Steam Flow Rate - kg/h	37966	35290	37377	26310	26310	22680	31750	38560
Steam Production Rate kgs/kgr*	2.88	2.6	2.81	2.64	2.64	3.33	3.58	3.77
Flue Gas Flow Rate - m^3/h	113700	114530	101300	157220	163155	159710	154780	171260
Carbon Dioxide Content in Flue Gas (%)	5.8	5.6	5.7	6.8	7.1	6.2	8.5	9.0
Burning Rate (tonne/day)	-	-	-		239	239	163	213 245

(1) Unit #1: By Provincial Government (See Sections 8.2.1 and 8.2.2)

* kgs - kilogram of steam
  kgr - kilogram of refuse

The Pilot Test Stage

Following the publication of the Shawinigan assessment report, the CUQ modified the secondary air ports and at the same time installed the prototype arch. These modifications were carried out on Unit #1 in October 1978.

In late October 1978, with the temporary arch in place, emissions testing was again carried out by the Quebec provincial government. The results of these tests are also shown in Table 8.1. During Tests 2 and 3, the crane operator removed all larger unburnable items, such as steel drums, refrigerators, water tanks, etc. and stored them for disposal rather than feeding them to the units.

It is interesting to note the dramatic difference between the results of the tests before and after the modifications were made, i.e., May and October 1978, respectively. The amounts of particulate emissions and excess air significantly decreased after the modifications were in place, even at the relatively higher steam rates of tests 2 and 3. The following discussion briefly reviews each of the "after modifications" (October 1978) tests:

i)   During the first October test run, secondary air was not used, and almost all primary air was supplied to the burning grate. Apparently because of the introduction of large unburnable objects, only 22,680 kg of steam per hour could be produced. The conclusion derived from the results of this first test was that the reduction of the emissions as compared to May 1978 tests was due primarily to the installation of the arch.

ii) During the second test run, there was a reduction of the excess air to the 130% level; secondary air was utilized, and primary air was reduced. The conclusions drawn from the results of the second test were as follows:

     a)   good distribution and utilization of secondary air was experienced,
     b)   better retention time under the arch was demonstrated, and
     c)   reduction of the emissions resulted.

iii) The third test was specifically designed to determine the effect that a high burning/steam production rate (38,500 kg/h) would have on particulate emission rates. The effect of producing 20% more steam was to more than double the particulate emission concentration.

Based on the "before and "after" tests, the combustion efficiency improved on average by 14%, while steam production improved by 35% even though the gas flow rates were within 1% of each other. It appears, however, that there were more differences between the "before" and "after" tests than could be attributed solely to the installation of the arch.

The Shawinigan report concluded that with good utilization of the primary and secondary air, and improvement of the temperature and retention time in the furnace (presumably because of the arch), a reduction of the emissions and improvement in combustion efficiency had been demonstrated.

8.2.3   Provincial Government Testing Program - 1982

Stack sampling of particulate and HCl emissions in the stack was carried out in November 1982 by the Provincial Government. The test results are presented in Table 8.2.

TABLE 8.2
Provincial Government Stack Testing Program - 1982[1]

Test Run No.	Emission Particulate (mg/Nm^3)*	Emission HC1 (ppm)*	Flue Gas Flow Rate (m^3/h)	Exhaust Temperature °C	Flue Gas Composition	
					CO_2 %	Moisture %
1	180.5	526	423700	118.6	4.5	8.0
2	185.2	503	289700	257.7	8.1	15.2
3	152.8	881	279600	254.9	7.6	5.5

(1) See Section 8.2.3
Two units in operation
*   Corrected to 12% CO_2

During the first test run, two incinerator units were in operation, and the exhaust fan of a third unit was running. For the last two test runs, only two units were in operation. During the sampling program, each incinerator unit produced an average of 31,750 kg/h of steam.

The report concludes that the Quebec Incinerator particulate emissions were under the emission concentration standard of 270 mg/Nm³ corrected to 12% CO_2, but over the regulated HCl concentration of 500 ppm. The report recommended that a wet scrubbing system be installed on the incinerator in order to reduce the emission of acid gases and particulates.

8.2.4   Roche Stack Testing Program - 1984

Between October 29 and November 6, 1984, Roche Envirobec completed a series of 18 stack tests. This program consisted of two phases. Phase I measured the particulate emissions concentration and calculated the particulate removal efficiency of the electrostatic precipitator.   Phase II measured particle size distribution in the exhaust gas after the electrostatic precipitator, paying particular attention to the unburned material and large particulates.

The sampling program was carried out on incinerator Units #1 and #4 under normal operating conditions, and on Unit #1 under high steam production conditions. The program assumed that the efficiencies of Precipitators #2 and #3 would be similar to that found for Units #1 and #4. This was thought to be a reasonable assumption in view of the Joy Manufacturing report (September 1984) which indicated that all four precipitators were in good condition.

Table 8.3 presents a summary of the emissions and precipitator efficiencies found in Phase I of the test program. Table 8.4 presents some data from Phase II including the weight percentages encountered for particulates greater than 12 m during the particle size distribution test runs. There was some concern related to the emission of large particulates. Analysis of the composition of the collected particulates greater than 5 m showed unburned carbon content which exceeds the provincial regulation of 10% for unburned material.

TABLE 8.4

Roche Performance Size Distribution Testing[1]

Test Run No.	Unit Under Test	Exhaust Temperature °C	Flue Gas Composition			% By Weight >12
			O_2 %	CO_2 %	Moisture %	
4	4	290	11.1	8.7	18	92.1
5	4	278	12.0	7.8	18	-
6	4	286	8.0	11.8	18	57.2
10	1	256	11.1	8.7	18	71.9
11	1	258	12.7	7.2	18	54.8
12	1	260	11.0	8.8	18	61.6
14*	1	256	1.3	8.5	18	38.4
15*	1	258	1.9	7.9	18	33.0
16*	1	253	11.2	8.6	18	25.1

* High Steam Flow
(1) Oct. to Nov. 1984 one unit in operation (See Section 8.2.4)

TABLE 8.3

Roche Performance Testing Program[1]

Test Run No.	Unit Under Test	Particulate Emission Concentration mg/Nm^3	Flue Gas Flow Rate (m^3/h)	Steam Flow Rate kg/h	Exhaust Temperature $^{\circ}$C	Flue Gas Composition			Precipitator Collector Efficiency
						O$_2$ %	CO$_2$ %	Moisture %	
1	4	150	165210	25675	294	13.1	6.7	13.0	97.7
2	4	101	152160	30935	293	11.9	7.9	14.3	97.8
3	4	57	136280	33660	282	11.4	8.7	18.0	98.6
7	1	128	115540	34135	246	13.5	6.3	15.4	96.8
8	1	148	114120	34110	245	13.6	6.4	15.8	95.6
9	1	196	126060	33840	255	12.3	7.6	18.0	95.6
13*	1	97	140120	36470	252	12.0	8.1	18.1	97.7
17*	1	97	144980	32480	252	10.8	9.0	16.7	97.8
18*	1	147	149530	34790	258	11.2	8.6	16.1	96.8

* High Steam Flow

(1) Oct. to Nov. 1984 one unit in operation (See Section 8.2.4)

** Corrected to 12% CO$_2$

8.2.5   Provincial Government Testing Program - 1985

Stack sampling for dioxin and furan emissions in the stack was carried out by the Provincial Government in December 1985, with two units in operation. The test results are presented in Table 8.5, the emissions for each isomer can be found in Appendix D. The estimated refuse feed rate for the test was 11.5 tonnes per hour per unit.

TABLE 8.5
Provincial Government Testing Program - 1985[1]

Dioxins Emissions

Test	mg/Nm3*	mg/h	mg/t of refuse
1	1143	107	4.6
2	836	83	3.6
3	3977	322	14.0

Furans Emission

Test	mg/Nm3*	mg/h	mg/t of refuse
1	225	21	0.9
2	163.7	16	0.7
3	1039	84	3.6

* Corrected to 12% CO_2
(1) See Section 8.2.5

8.2.6   The Consortium Roche/Lavalin Testing Program - 1986

In view of the importance to the CUQ to reduce the Quebec Incinerator emissions and in particular eliminate the fallout problem resulting from the escape of large particulates, the consortium Roche/Lavalin measured the emission of particulates in April/June 1986, in parallel with the NITEP program. The principal objective was to verify that the furnace modifications to Unit #4 had a beneficial effect on the emissions of particulates.

To accomplish this objective, hi-vol equipment was used to measure particulates at the outlets of Units #1 and #4. The sampling was not done simultaneously but rather in an alternating fashion (i.e. first day, Unit #4, second day, Unit #1, third day, Unit #4, etc.). The hi-vol was utilized for these tests because its design (ie. 5 cm nozzle) permits the capture of large unbroken particulates whereas the standard isokinetic train (0.95 cm nozzle) does not. These tests were conducted at one average velocity point. For process variation effects, the intent was simply to achieve a first order comparison of the two furnace configurations.

As shown in Tables 8.6 and 8.7, the furnace modifications showed dramatic improvements, resulting in a reduction of over 95% of the particulate emissions rate. Table 8.6 also presents a good correlation between the particulate emission measured by the regular sampling train (NITEP test) and the Hi-Vol measurement.

TABLE 8.6
HI - Vol Emission Summary[1]

| UNIT NO. 4 (MODIFIED) | | | | UNIT NO. 1 | | | |
TEST	DATE	HI-VOL mg/Nm^3*	UNBUR. %	NITEP RESULT	TEST	DATE	HI-VOL mg/Nm^3*	UNBUR. %
1	86-06-27	35	24	26	5	86-06-30	1215	11
2	86-06-27	49	44	26	6	86-06-30	830	13
3	86-06-29	70	19	46	11	86-07-04	917	
4	86-06-29	56	19	46	12	86-07-04	1112	12
7	86-07-02	27	15	34	13	86-07-07	720	14
8	86-07-02	21	23	34	14	86-07-07	1030	14
9	86-07-03	38	9	39	15	86-07-09	1252	15
10	86-07-03	30	20	39	16	86-07-09	1689	14
19	86-07-11	83	8	80	17	86-07-10	989	16
20	86-07-11	56	21	80	18	86-07-10	1146	12
AVERAGE =		46		45			1090	

* All concentrations corrected to 12% CO_2
(1) Roche - Lavalin 1986 (See Section 8.2.6)

TABLE 8.7

Process Parameters[1]

TEST	DATE	UNIT	STEAM PRESSURE (kPa)	STEAM TEMPERATURE (°C)	STEAM FLOW (t/h)	FURNACE TEMPERATURE (°C)	EXHAUST TEMPERATURE (°C)	O₂ (%)
1	86-06-27	4	4247	319	20,0	848	199	12,6
2	86-06-27	4	4247	319	20,0	848	199	12,6
3	86-06-29	4	4282	321	27,6	849	232	12,2
4	86-06-29	4	4282	321	27,6	849	232	12,2
5	86-06-30	1	4585	324	30,2	704	264	11,0
6	86-06-30	1	4585	324	30,2	677	273	11,7
7	86-07-02	4	4297	321	28,1	1030	212	9,1
8	86-07-02	4	4297	321	28,1	1030	212	9,1
9	86-07-03	4	4396	323	31,8	1085	220	9,8
10	86-07-03	4	4396	323	31,8	1085	220	9,8
11	86-07-04	1	4689	324	29,1	732	275	12,0
12	86-07-04	1	4689	324	28,2	760	277	12,0
13	86-07-07	1	4550	324	31,5	843	279	10,7
14	86-07-07	1	4550	324	30,9	704	279	11,2
15	86-07-09	1	4585	324	27,4	704	284	11,8
16	87-07-09	1	4620	324	29,8	732	286	12,0
17	86-07-10	1	4620	324	30,5	760	280	11,6
18	86-07-10	1	4620	324	31,1	723	286	11,4
19	86-07-11	4	4328	322	28,5	990	232	11,6
20	86-07-11	4	4328	322	28,5	990	232	11,6

(1) During Roche - Lavalin Tests, 1986 (See Section 8.2.6)

9.0 CHARACTERIZATION TEST

9.1 OVERVIEW

The Characterization Test (CT) program was performed to establish an optimum test matrix to be followed during the subsequent "Performance Tests" (PTs). In addition, it served to familiarize the testing team with the incineration system, and to prove the workability of the testing methodologies proposed.

This chapter presents the results of the Characterization Test program (Section 9.2) and the rationale for selecting the Performance Test matrix (Section 9.3).

Nineteen Characterization Tests were completed, providing results which demonstrated how the incineration system performed over a wide range of operating conditions.

The following shows the wide range of test run average values that were obtained for various parameters during the Characterization Test Runs:

Steam Rate	20.2 to 32.1 tonne/hour
Excess Air Level	40 to 162%
Radiation Chamber Temperature	805 to 1099°C
Primary/Secondary Air Ratio	56:44 to 94:6
Carbon Monoxide level	16 to 237 ppm
Carbon Dioxide level	7 to 12%
Total Hydrocarbons - hot	4 to 43 ppm
- cold	2 to 7 ppm
Hydrogen Chloride	155 to 966 ppm
Sulfur Oxides (SO_2)	90 to 255 ppm
Nitrogen Oxides	136 to 234 ppm
Combustion Efficiency	99.80 to 99.99

The above concentrations are corrected to 12% CO_2.

Ultimately five distinct operating modes demonstrated during the Characterization Tests were selected as the basis for the subsequent Performance Test phase. These five operating modes were selected so that the Performance Tests would cover as many areas of interest as practical, considering the needs of incinerator designers, operators, owners, environmental approvals agencies and the Scientific Authority.

The Characterization Test phase identified settings for process and operating parameters that were required to obtain the various operating modes of interest. Each test was assessed considering steam

rate, combustion air distribution, grate speeds, operating temperatures, continuous gas analyzer readings, visual observations, upset effects, etc.

The following provides a brief review of the parameters that were used to evaluate the system's performance during the Characterization Test phase. Reference is made to Chapter 3 for a more detailed discussion.

Performance Evaluation Parameters

The Characterization Test results were assessed primarily based on the following four process parameters:

(i)   steam rate,
(ii)   excess air,
(iii)   radiation chamber temperatures, and
(iv)   primary/secondary combustion air ratio.

These particular parameters were chosen for two reasons. Firstly, each could be readily varied with the computerized control system set-point adjustments, and secondly, all other monitored process parameters either resulted from the four primary process parameter settings or had less impact on the operating mode.

The interaction between these parameters was observed and analyzed at three different steam or refuse feed reed rates (70%, 100% and 115% of design), under conditions that the combustion experts classified as either good or poor operating modes. The incinerator refuse feed rate was maintained at the desired low, design, and high refuse feed rates (20, 28 and 32 tonnes of steam per hour, respectively) by setting the automatic control system to the desired steam rate.

Continuous gas emission data results for carbon monoxide (CO) levels were also utilized extensively in evaluating differences between Characterization Test runs. Generally high CO levels were utilized to classify operating modes as representing poor combustion conditions, while low levels indicated good combustion conditions. Other continuously monitored emissions were reviewed, however they did not provide the clear differentiation between operating modes that the CO levels provided.

In the following sections, reference is made to a "sister test". This term applies to a particular test that experienced similar process results as another test that was completed at the same steam rate.

9.2   REVIEW OF CHARACTERIZATION TEST RESULTS

9.2.1   General

The Characterization Tests were divided into three distinct groups, based on the refuse steam rate. Of the nineteen Characterization Tests, four were performed at the low rate (20 t/h steam rate), eight were performed at the design rate (28 t/h steam rate), and seven were performed at the high rate (32 t/h steam rate).

The sub-grouping for each of the three test groups is shown in Figure 9.1. Subgroups were established on the basis of low and high excess air operation; each was further sub-divided into comparative radiation chamber temperature levels.

Table 9.1 summarizes the results of the Characterization Test runs. All values shown are average values resulting from the specific test period.

A detailed description of each Characterization Test is presented in Appendix B of this report. The following sections summarize and briefly review the results of each test in relation to its mode of operation or steam rate. The basis for selecting the PT matrix from these results is presented in Section 9.3.

9.2.2   Low Steam Rate Tests

Four Characterization Tests (CT-01, CT-02, CT-18, and CT-19) were conducted at the low feed rate of 20 tonnes of steam per hour. The tests subgroupings at this feed rate are shown graphically in Figure 9.2.

Based on a review of Table 9.2, results documented in the detailed test descriptions in Appendix B and the detailed field data presented in Volume IV, the following observations were noted:

i)   Generally this family of tests demonstrated that this mass burning incinerator technology could be operated successfully at this relatively low feed rate (30% below the design rate).

ii)   CT-01's radiation chamber temperature of 805°C was lower than that generally considered appropriate for good combustion although the resulting CO level was reasonably low at 65 ppm corrected to 12% CO_2.

iii)   CT-02 was operated at a very low excess air level in order to increase the radiation chamber temperature from the CT-01 level. The results indicated that while the temperature increased significantly to 962°C, this test resulted in a significant increase in carbon monoxide (CO)

Feed Rate: **Low** **Design** **High**

Excess Air Rate: Low High Low High Low High

Radiation
Chamber
Temperature

Low | High | Low | Low | High | Very Low | Low | High | High | Very High | Low | High

Characterization Tests

CTØ1 | CTØ2 | CT18, CT19 | CTØ3, CTØ4, CTØ8 | CT11, CT16 | CTØ7 | CT17 | CT12 | CTØ6 CTØ9 | CT15 CT14 | CTØ5 | CT13, CT10

CT- | Ultimately selected as basis for Performance Test operating mode

Figure 9.1

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Characterization Test Operating Models

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TABLE 9.1 : CHARACTERIZATION TEST RUN PROCESS AVERAGE VALUES

CHARACTERIZATION TEST #:		CT01	CT02	CT03	CT04	CT05	CT06	CT07	CT08	CT09	CT10	CT11	CT12	CT13	CT14	CT15	CT16	CT17	CT18	CT19
REFUSE LOADING MODE:		LOW	LOW	DESIGN	DESIGN	HIGH	HIGH	DESIGN	DESIGN	HIGH	HIGH	DESIGN	DESIGN	HIGH	HIGH	HIGH	DESIGN	DESIGN	LOW	LOW
Steam Rate (tonne/hr)		20.2	20.3	27.5	25.5	30.7	32.1	27.5	28.1	31.9	32.1	27.9	27.6	32.0	31.8	31.9	27.9	27.9	20.5	21.1
Refuse Feed Rate (tonne/hr)		NA	6.3	8.5	9.2	11.3	11.3	7.1	10.2	8.8	12.4	8.9	12.3	9.4	11.4	11.4	8.4	6.7	9.8	NA
Steaming Ratio (TSt/TRef)		NA	3.22	3.24	2.77	2.72	2.84	3.87	2.75	3.62	2.59	3.13	2.24	3.40	2.79	2.80	3.32	4.16	2.09	NA
Total Combustion Air (Am3/min)		300	298	530	683	812	543	846	599	694	810	529	751	789	834	559	470	728	591	508
Combustion Air Distribution:																				
-Primary/Secondary Ratio		63:37	56:44	58:42	63:37	79:21	69:31	94:06	71:29	72:28	71:29	70:30	92:08	94:06	61:39	66:34	72:28	77:23	92:08	56:44
-Secondary Front/Rear Ratio		46:54	46:54	77:23	69:31	29:71	29:71	74:26	94:06	78:22	60:40	34:66	77:23	76:24	65:35	36:64	33:67	29:71	73:27	87:13
Temperatures (deg C) :																				
-Lower Radiation Chamber		805	962	970	925	927	1030	884	945	993	986	1071	961	960	935	1099	1062	927	846	845
-Upper Radiation Chamber		NA	650	NA	692	668	727	649	705	713	707	725	686	694	676	734	743	663	610	648
-Radiation Chamber Grid		805	732	851	840	787	861	736	764	755	747	750	725	682	675	725	718	676	582	605
-Boiler Inlet Grid		775	795	792	771	750	824	712	780	819	790	817	740	777	750	838	813	720	659	703
-Stack		192	187	200	209	222	207	235	220	231	237	216	230	236	235	214	209	231	212	208
Combustion Efficiency (%)		99.95	99.86	99.97	99.95	99.84	99.93	99.80	99.96	99.90	99.91	99.88	99.85	99.90	99.90	99.92	99.93	99.91	99.89	99.98
Continuous Flue Gas Data [corr.to 12% CO2]:																				
Carbon Dioxide	%	11	12	10	10	9	11	7	9	11	9	10	8	9	9	11	10	9	7	9
Carbon Monoxide	ppm	65	163	34	57	194	81	237	48	120	110	145	182	114	115	95	84	106	132	16
Oxygen (dry basis)	%	9	6	10	10	11	9	12	11	9	11	10	12	11	11	9	10	12	13	12
THC cold	ppm	4	7	3	4	3	3	5	3	7	4	4	4	2	3	3	5	4	4	3
THC hot	ppm	12	11	20	15	29	20	40	18	NA	NA	43	31	7	4	4	NA	17	16	NA
SO2	ppm	213	196	159	171	123	206	251	98	90	172	227	112	206	184	185	135	255	145	149
NOX	ppm	153	136	173	197	189	166	210	215	198	192	149	157	186	234	171	159	207	175	217
HCl	ppm	201	155	240	322	249	287	966	377	238	284	479	384	498	497	314	366	462	193	312
Excess Air	%	76	40	82	92	106	69	133	96	75	102	88	125	102	108	68	79	123	162	135
Opacity	%	NA	NA	32	31	32	31	38	33	33	37	34	37	27	29	26	26	31	28	29

Notes: 1. Shaded columns represent the Characterization test conditions that were ultimately selected as operating conditions to be tested during the Performance Testing Program.
2. Characterization test CT-12 results were considered to be misleading and should be disregarded from any operating condition evaluation.
3. NA = Not Available

Low Load
20.2 to 21.1 t/h steam

Low Excess Air
76% to 96%

High Excess Air
162%   134%

Low Temperature
805°C

High Temperature
962°C

Low Temperature
846°C   845°C

P/S Air
63/37
CT∅1

P/S Air
56/44
CT∅2

P/S Air
92/08
CT18

P/S Air
56/44
CT19

▓ selected as PT operating mode

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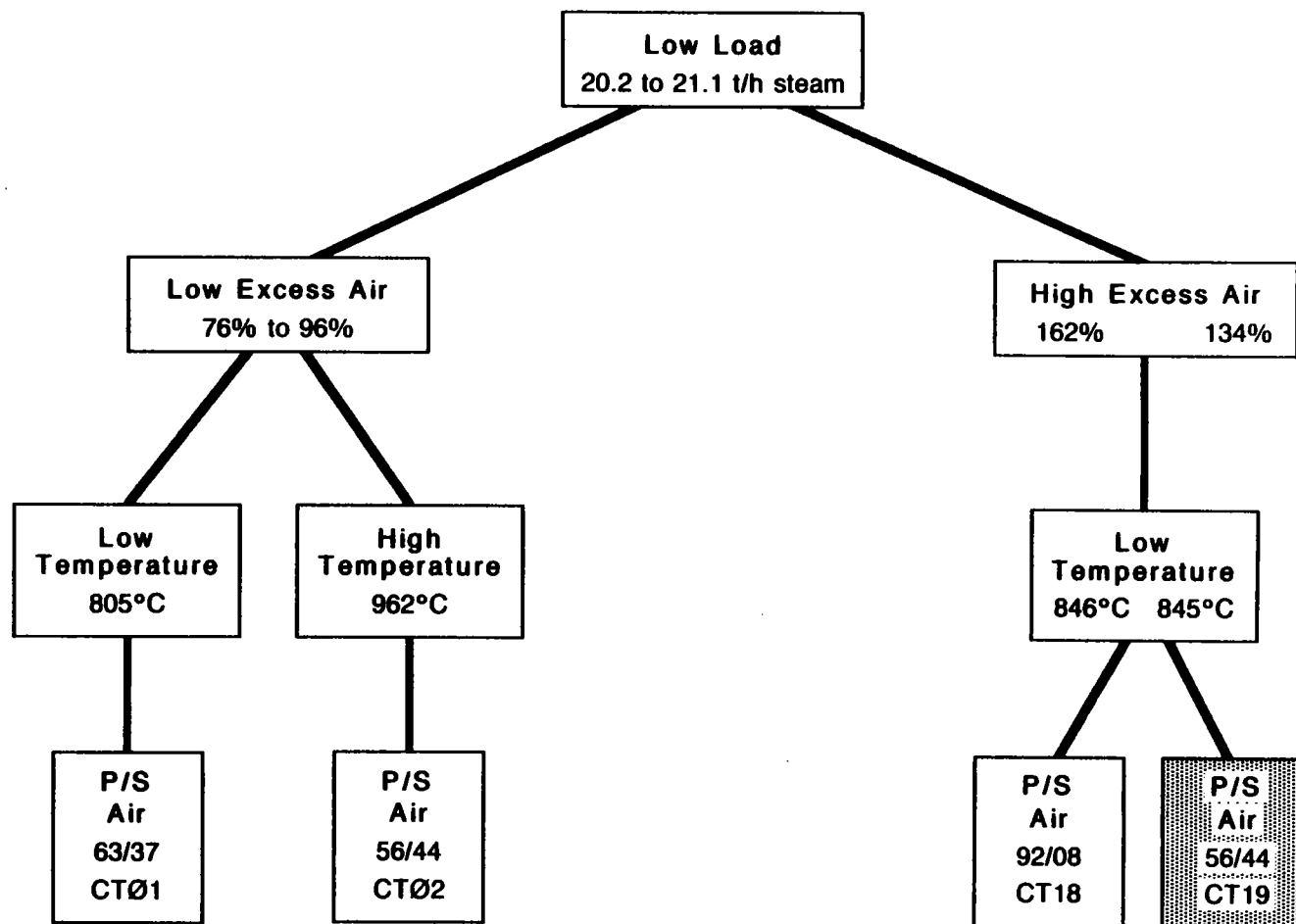
Figure 9.2
QUEBEC INCINERATOR
Characterization Test Conditions
NITEP – Quebec

emissions to 163 ppm corrected to 12% CO_2. During the test run, several peaks up to 300 ppm (corrected to 12% CO_2) occurred. CO levels versus time are shown for CT-02 in Figure 9.3.

iv) CT-18 was conducted at a high primary to secondary air ratio (minimum secondary air rate). The results show that a decrease in temperature to 846°C resulted and CO emissions remained relatively high at 132 ppm corrected to 12% CO_2. It appears that the excess air level of 162% with the low secondary air rate and resulting lower temperature was not appropriate for good combustion.

v) CT-19 was operated at a lower excess air level with a better ratio between primary and secondary air flows (56:44) as compared to its sister test, CT-18 (92:8). Lower radiation temperatures were virtually the same. The results of this test showed a significant decrease in CO to 16 ppm corrected to 12% CO_2.

vi) The CT-19 average radiation chamber temperature of 845°C was higher than CT-01 at 805°C even though excess air levels were higher for CT-19 (135% vs 76%). This testing mode was ultimately selected as a Performance Test condition.

TABLE 9.2
LOW FEED RATE PROCESS PARAMETERS

	FEED RATE t/h	STEAM RATE t/h	EXCESS AIR %	PRIMARY/ SECONDARY RATIO	LOWER RADIATION CHAMBER TEMP. C°	CARBON MONOXIDE ppm
CT-01	N/A	20.2	76	63:37	805 *	65
CT-02	6.3	20.3	40	56:44	962	163
CT-18	9.8	20.5	162	92:08	846	132
CT-19	N/A	21.1	134	56:44	844	16
AVERAGE		20.5	103	67:33	864	94

N/A - not available due to weigh scale downtime * - approximate average based upon the Bailey produced temperature graphics

9.2.3 Design Steam Rate Tests

Eight Characterization Tests were conducted at the design rate of 28 tonnes of steam per hour. The test subgroupings at this rate are shown graphically in Figure 9.4. The refuse feed rate, steam rate, excess air level, primary/secondary air ratio, lower radiation chamber temperature, and carbon monoxide (CO) concentration for each design steam rate CT test are shown in Table 9.3.

Fig. 9.3: CO and THC (hot and cold)
5-Minute Averages
RUN : CT02

```
                    ┌─────────────────────────┐
                    │       Design Load       │
                    │   25.5 to 28.1 t/h steam │
                    └─────────────────────────┘
```

Design Load
25.5 to 28.1 t/h steam

Low Excess Air
79% to 96%

High Excess Air
123% to 133%

Low Temperature
925 to 970°C

High Temperature
1062 to 1071°C

Very Low Temperature
884°C

Low Temperature
927°C

High Temperature
961°C

P/S Air
58/42
CTØ3

P/S Air
71/29
CTØ8

P/S Air
63/37
CTØ4

P/S Air
70/30
CT11

P/S Air
72/28
CT16

P/S Air
94/06
CTØ7

P/S Air
77/23
CT17

P/S Air
92/08
CT12
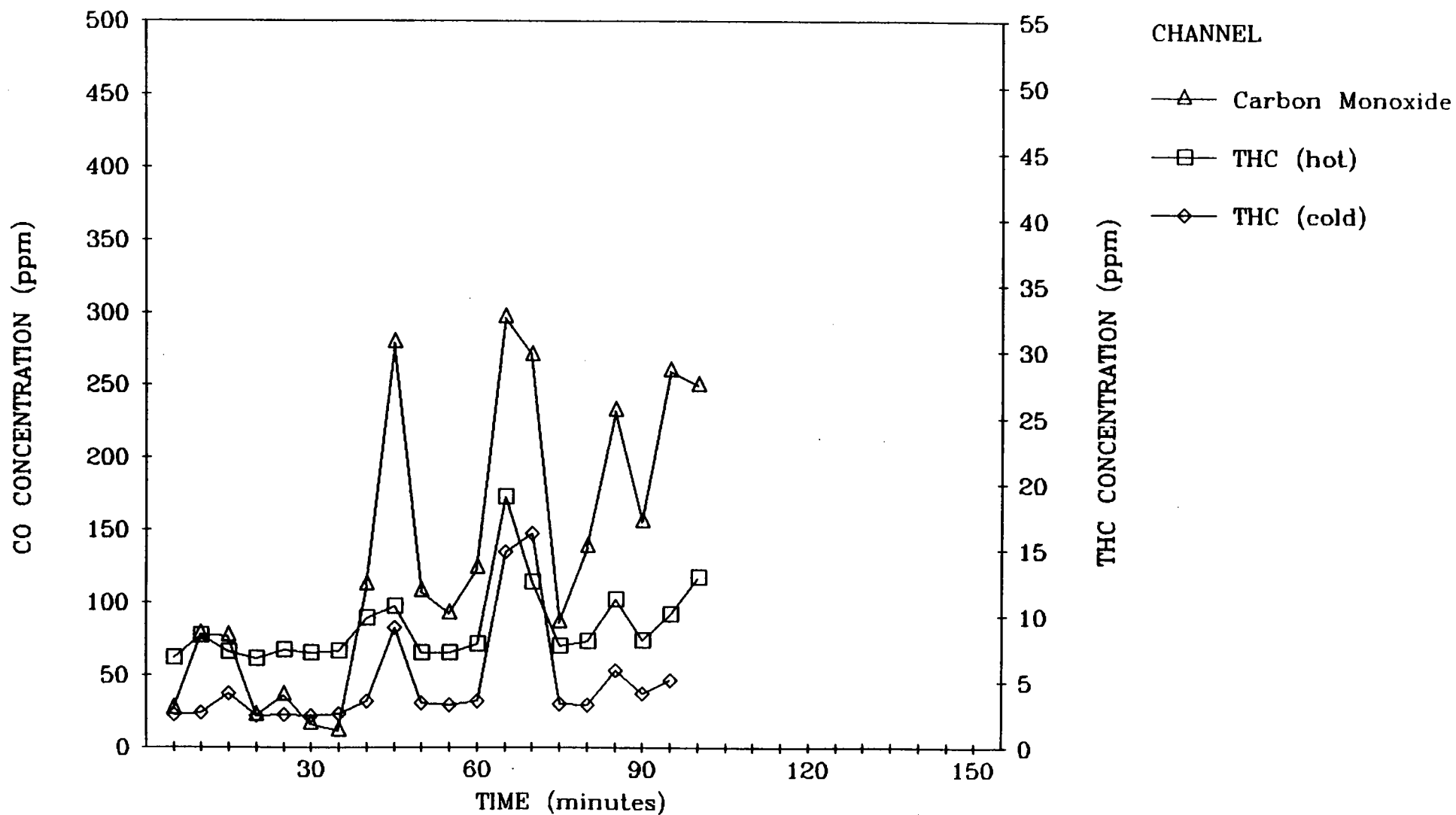
▓ selected as PT operating mode

Figure 9.4

QUEBEC INCINERATOR

Characterization Test Conditions

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TABLE 9.3
DESIGN FEED RATE PROCESS PARAMETERS

	FEED RATE t/h	STEAM RATE t/h	EXCESS AIR %	PRIMARY/ SECONDARY RATIO	LOWER RADIATION CHAMBER TEMP. C°	CARBON MONOXIDE ppm
CT-03	8.5	24.0	82	58:42	970 **	34
CT-04	9.2	25.5	92	63:37	926	57
CT-07	7.1	27.5	133	94:06	883	237
CT-08	10.2	28.1	95	71:29	945	48
CT-11	8.9	27.9	88	70:30	1071	144
CT-12	12.3	27.6	125	92:08	961	182
CT-16	8.4	27.9	79	72:28	1062	84
CT-17	6.7	27.9	123	77:23	927	106
AVERAGE	8.9	27.1	102	75:25	968	111

* These temperatures represent the average taken from the lower chamber process thermocouples
** This is an approximate average based on the Bailey-produced temperature graphics (CT-03 only).

Based on a review of Table 9.3, the results documented in the detailed test descriptions in Appendix B and the detailed field data presented in Volume IV, the following observations were noted:

i) CT-03 was controlled at a fixed 58:42 primary/secondary air ratio. The results indicated that this control mode can produce good combustion conditions with low excess air and low CO emissions. The combustion experts considered that the automatic temperature control (ATC) of the primary/secondary air ratio provided the most responsive control of radiation chamber temperature as the quality of the refuse varied (i.e. the fixed ratio control mode permitted excessive radiation chamber temperature variations to occur as refuse quality changed). To maintain target operation temperatures, subsequent tests were therefore operated on ATC.

ii) CT-04 achieved similar results to those found during CT-03 however this test was marred by swings in combustion conditions; hence no definitive conclusions could be drawn from this test run. The test was originally intended to demonstrate results at a high excess air level as well as to evaluate manual versus automatic control grate speed differences. In fact, low excess air levels occurred and high peak CO levels resulted from unstable process conditions that occurred during the grate speed control mode switchover. During the manual operation phase, the grate speeds were relatively low and the combustion air rate appeared to be generally excessive. On automatic grate speed control, more refuse was fed; primary air rates decreased and radiation chamber temperatures rose as a result of the grate speed control satisfying the O_2 set-point.

iii) CT-07 was the first test deliberately designed to demonstrate poor performance at the design rate. The excess air control set-point was set inordinately high, resulting in an extreme primary/secondary air split and relatively low radiation chamber temperature. The results of this test confirmed that the intended poor results could be obtained. The CO emissions at 237 ppm (at 12% CO_2) on average, were the highest of all Characterization Tests conducted, including

those conducted at the low and high steam rates. This operating mode was ultimately selected as a Performance Test condition to assess poor operations with poor air distribution (i.e. very little to no secondary air).

iv) CT-08 was conducted under low excess air and medium lower radiation chamber temperature conditions, thereby potentially providing reasonable burn conditions. All other process parameters were adjusted to set-points considered to be optimal at this test stage, including air distribution, grate speeds, excess air and automatic temperature control. The results of this test indicated that CO levels were the second lowest for this family of tests and the third lowest for all of the Characterization Tests. In addition, the medium level radiation chamber temperature provided a good primary/secondary ratio. In summary, this was an excellent test run and this operating mode was ultimately selected as the good operating mode Performance Test condition for the design steam rate. Ultimately, for Performance Testing the radiation chamber temperature target level was increased to 1000°C from the slightly lower levels experienced during CT-08 as discussed later, considering results for CT-16.

v) CT-11 was a high temperature test run with relatively low excess air, however a relatively high CO level resulted. Poor primary air distribution (i.e. high air flow in compartment 2A/2B) may have contributed to the high CO level.

vi) CT-12 was run with high excess air levels which resulted in a lower radiation chamber temperature as compared to CT-11. During this test, most of the combustion air was supplied as primary air with minimal secondary air supplied. This poor primary/secondary ratio seemed to be the cause of the relatively high CO levels obtained during this test. In comparison to CT-07, the higher radiation chamber temperature seemed to be consistent in relation to the lower CO levels obtained during this test. (CT-07 demonstrated relatively low radiation chamber temperatures and high CO emissions.) Both tests had poor primary/secondary air ratios. Poor speed selection for the grates (manual adjustment attempted) led to the conclusion that results during this test run were misleading.

vii) CT-16 was conducted at low excess air and high temperatures, with a reasonable primary/secondary air ratio (i.e. sufficient secondary air to complete combustion). The carbon monoxide emissions were relatively low but slightly higher than similar tests at lower radiation chamber temperatures (CT-03/-04/-08). As indicated in Appendix C, a short upset period occurred during this test. This upset resulted in a high CO concentration period, which elevated the overall test average. The upset was thought to be caused by rapid grate speed changes although a higher-than-average refuse heating value may have caused the upset as well. Without this upset, as shown in Figure 9.5, the CO levels for this operating mode were comparable to the best of the low temperature test levels experienced during CT-03, -04 and -08.

In summary, this operating condition demonstrated excess air levels below those of CT-08 resulting in relatively high temperature operation. If CO peaks could be avoided, comparatively low CO average levels could be expected. It was therefore decided that operating temperatures experienced during CT-08 should be increased by 40 to 60 C degrees. The 1000°C level generally recognized as appropriate for good combustion, thus became the good operating condition for the design rate.

viii) CT-17, having relatively low temperatures with high excess air, resulted in relatively high carbon monoxide emissions even though there was a reasonable amount of secondary air supplied. These conditions were selected for Performance Testing to demonstrate the performance under reasonable primary/secondary air ratio conditions with low radiation chamber temperatures. To ensure that the results of the Performance Tests would represent a distinct operating condition

Fig. 9.5: CO and THC (hot and cold)

5-Minute Averages
RUN : CT16
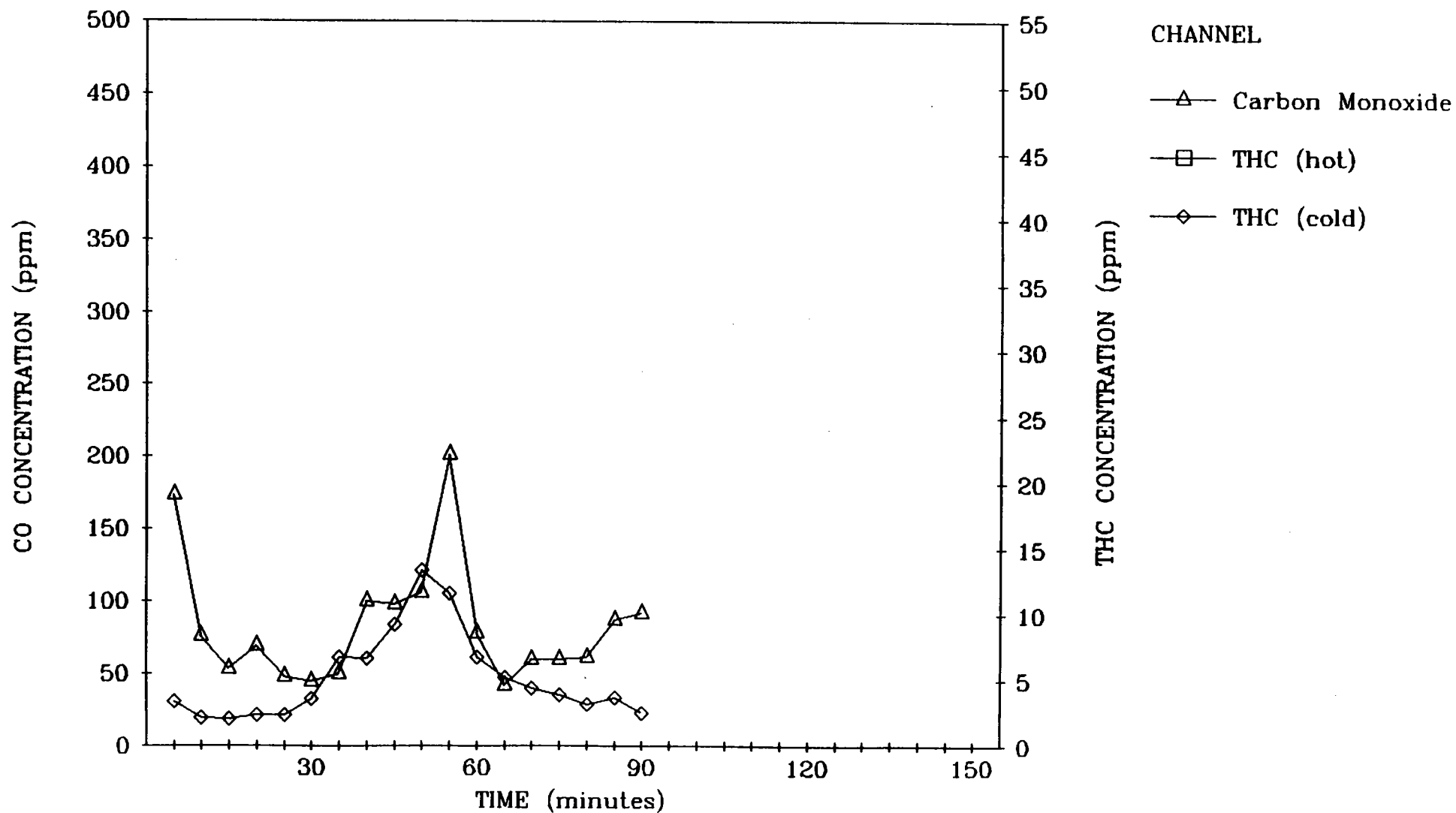
from that of compared to CT-08, the temperature differential was increased by aiming for lower temperatures for CT-17.
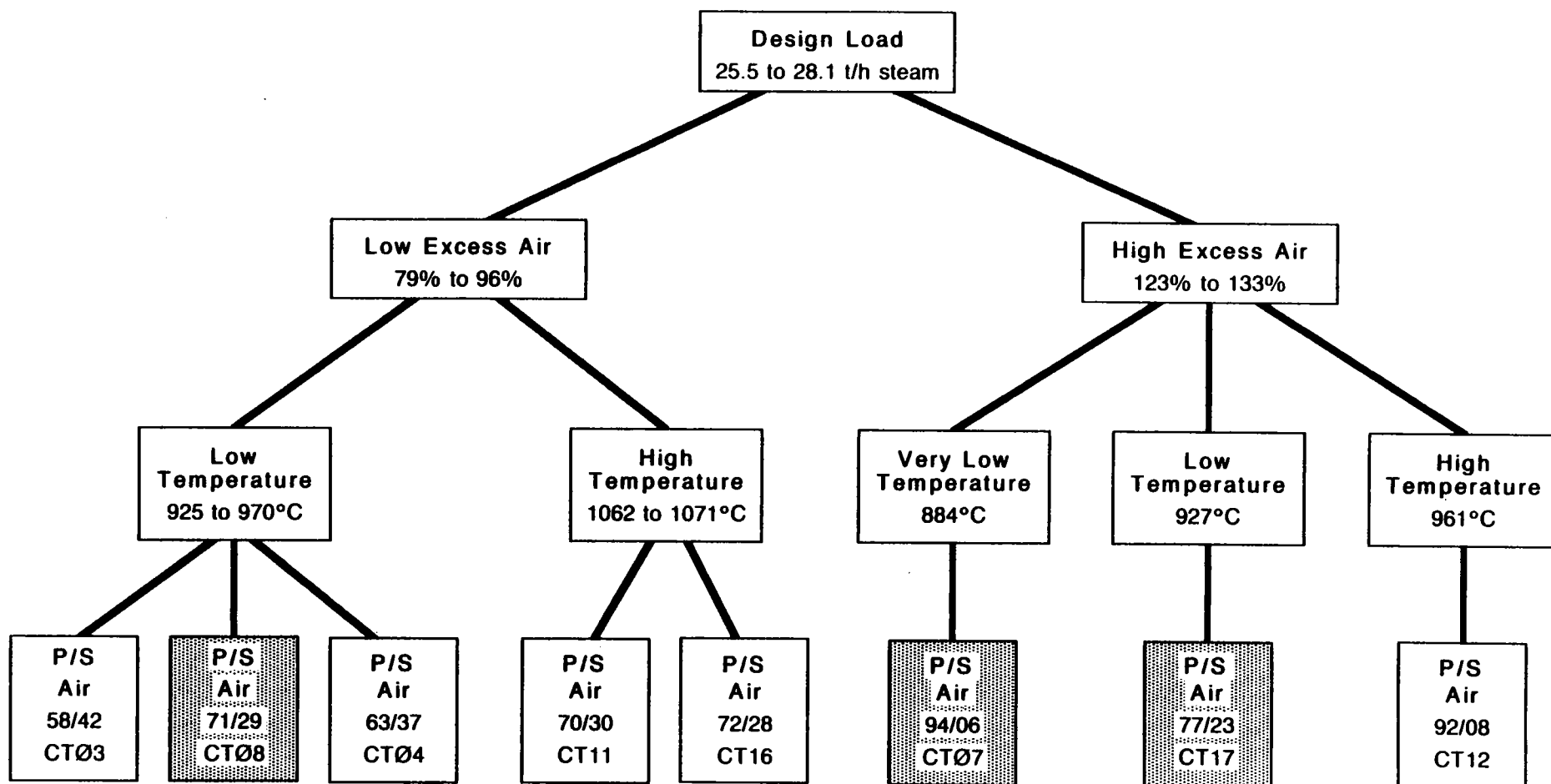
9.2.4   High Steam Rate Tests

Seven Characterization Tests were conducted at the high feed rate of 32 tonnes of steam per hour. The test subgroupings at this feed rate are shown in Figure 9.6. Refuse feed rate, steam rate, excess air level, primary/secondary air ratio, lower radiation chamber temperature, and carbon monoxide (CO) levels for each high steam rate CT test are shown in Table 9.4.

TABLE 9.4
HIGH FEED RATE PROCESS PARAMETERS

	FEED RATE t/h	STEAM RATE t/h	EXCESS AIR %	PRIMARY/ SECONDARY RATIO	LOWER RADIATION CHAMBER TEMP. C°	CARBON MONOXIDE ppm
CT-05	11.3	30.7	106	79:21	926	194
CT-06	11.3	32.1	69	69:31	1029	81
CT-09	8.8	31.9	74	72:28	993	120
CT-10	12.4	32.1	102	71:29	986	110
CT-13	9.4	32.0	102	94:06	960	114
CT-14	11.4	31.8	108	61:39	935	115
CT-15	11.4	31.9	68	66:34	1099	95
AVERAGE	10.9	31.8	90	73:27	990	118

* Temperatures listed are averages taken from the lower chamber process thermocouples

Based on a review of Table 9.4, the results documented in the detailed test descriptions in Appendix B and the detailed field data presented in Volume IV, the following observations were noted:

i)   Generally the incinerator operation was stable at this high feed rate. The plant operators were not concerned with operating the incinerator and auxiliary equipment, such as the induced draft fan and boiler, at this 15% over-capacity level. Long-term operation at this higher feed rate may result in increased equipment maintenance and more frequent forced shut-downs due to slagging in the grate zones and flame impingement on the boiler inlet tubes. However, at this feed rate and under good burning conditions, relatively low carbon monoxide concentrations were achieved.

ii) CT-05 was conducted under relatively low temperatures, high excess air conditions and a good primary/secondary air ratio. This test was carried out under manual grate speed control conditions. High CO emissions resulted, probably due to the unsteady combustion conditions

High Load
30.7 to 32.1 t/h steam

Low Excess Air
68% to 74%

High Excess Air
102 to 108%

High Temperature
1030°C 1099°C

Very High Temperature
1099°C

Low Temperature
927°C 935°C

High Temperature
960°C 986°C

P/S
Air
69/31
CTØ6

P/S
Air
72/28
CTØ9

P/S
Air
66/34
CT15

P/S
Air
79/21
CTØ5

P/S
Air
61/39
CT14

P/S
Air
94/06
CT13

P/S
Air
71/29
CT1Ø

▓ selected as PT operating mode

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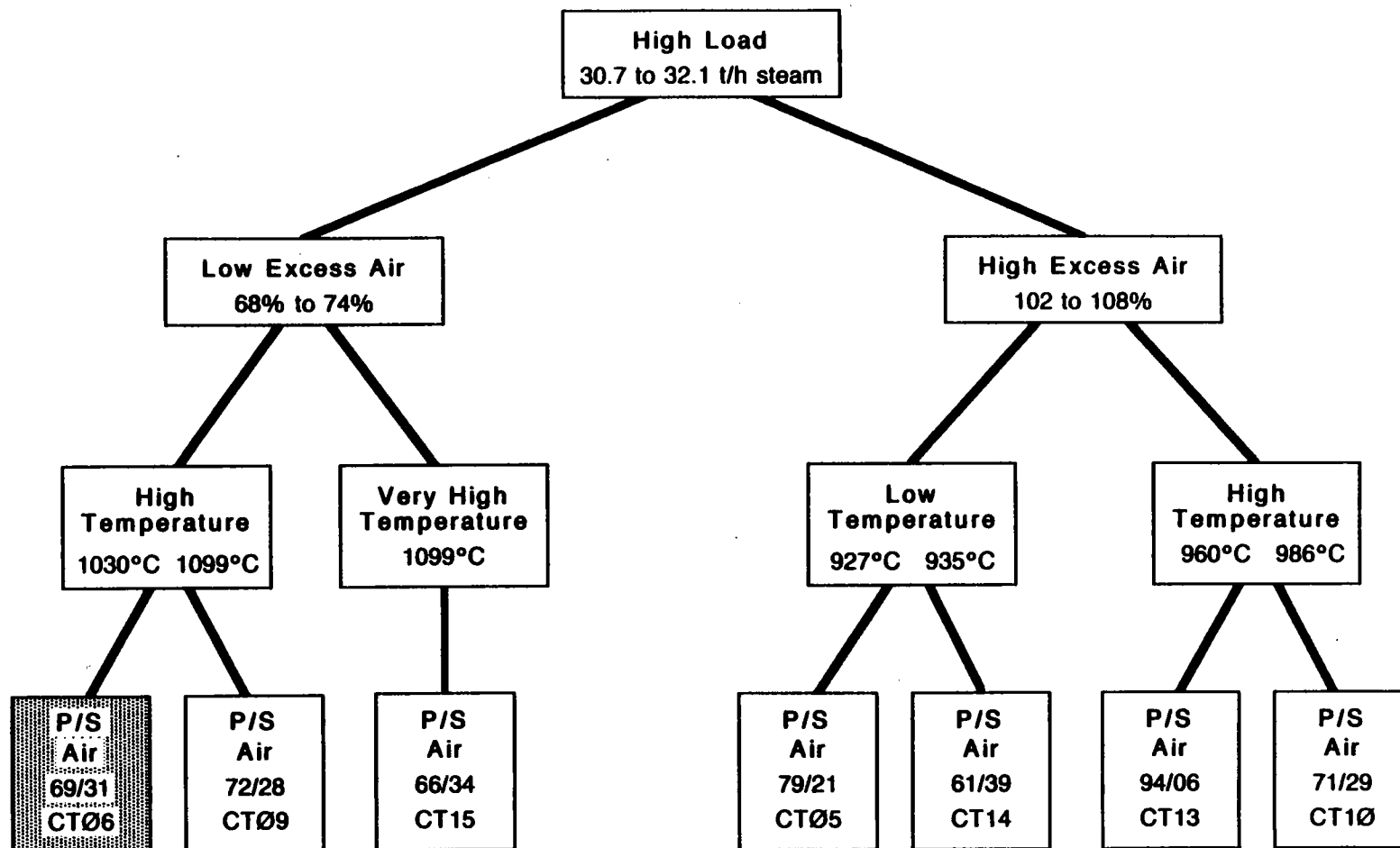
Figure 9.6
QUEBEC INCINERATOR
Characterization Test Conditions

caused by the manual grate operation. In addition, poor primary air distribution under the grates caused unusually high particulate lift-off from the burning pile (observed in the upper chamber section).

iii) CT-06 demonstrated a high temperature and low excess air operating mode. The results showed the lowest CO emissions experienced during the high steam rate tests. This operating test mode appeared to be optimum for the high steam rate operation and was selected as a Performance Test condition for good operation at a high load.

iv) CT-09 was conducted under low excess air conditions with the first half of the test period experiencing low temperatures and, the subsequent half experiencing higher temperatures, as shown in Figure 9.7. The lowest short-term CO emission levels were recorded during the high temperature period. No other significant differences occurred between temperature ranges.

v) CT-10 was conducted under high excess air and relatively high temperatures. A pre-test grate upset occurred which may have inflated the average CO levels recorded for the first part of the test.

vi) CT-13 was conducted under high excess air and relatively high temperatures. Results showed that the excess air levels, temperatures and CO concentrations were similar to those experienced during CT-10. The significant difference between CT-10 and CT-13 was that the primary/secondary air ratio was higher for CT-13 (94:06) vs. CT-10 (71:29). At this steam rate, higher CO levels were not experienced. At the design steam rate, the minimum secondary air condition had resulted in higher CO levels.

vii) CT-14 was conducted under high excess air and relatively low radiation chamber temperature conditions. Although the primary/secondary air ratio, temperature and excess air level were similar to its sister test, CT-05, the CO levels experienced were much lower, being similar to the CO levels experienced during other high excess air, higher temperature tests. Results during this test were influenced by the increased furnace wall slagging. This created an uneven burning bed profile, resulting in a relatively high drying grate speed during the first part of the test.

viii) CT-15 was conducted under low excess air, very high temperature test conditions. While the low excess air level and high temperatures appeared to cause more frequent CO peaks, as shown in Figure 9.8, the average CO level was relatively low and was similar to the results obtained during CT-06. This test seemed to confirm that the preferred operating mode at this high feed rate was under low excess air, high temperature conditions.

9.3 PERFORMANCE TEST RATIONALE

Five distinct operating conditions were identified for Performance Testing from the nineteen successfully completed Characterization Tests. The rationale for selecting particular Characterization Test conditions to be replicated during the Performance Tests are discussed hereafter.

Figure 9.7 : Temperature and CO versus time - CT-09

Radiation Chamber Temperatures
RUN : CT09

CO and THC (hot and cold)
RUN : CT09
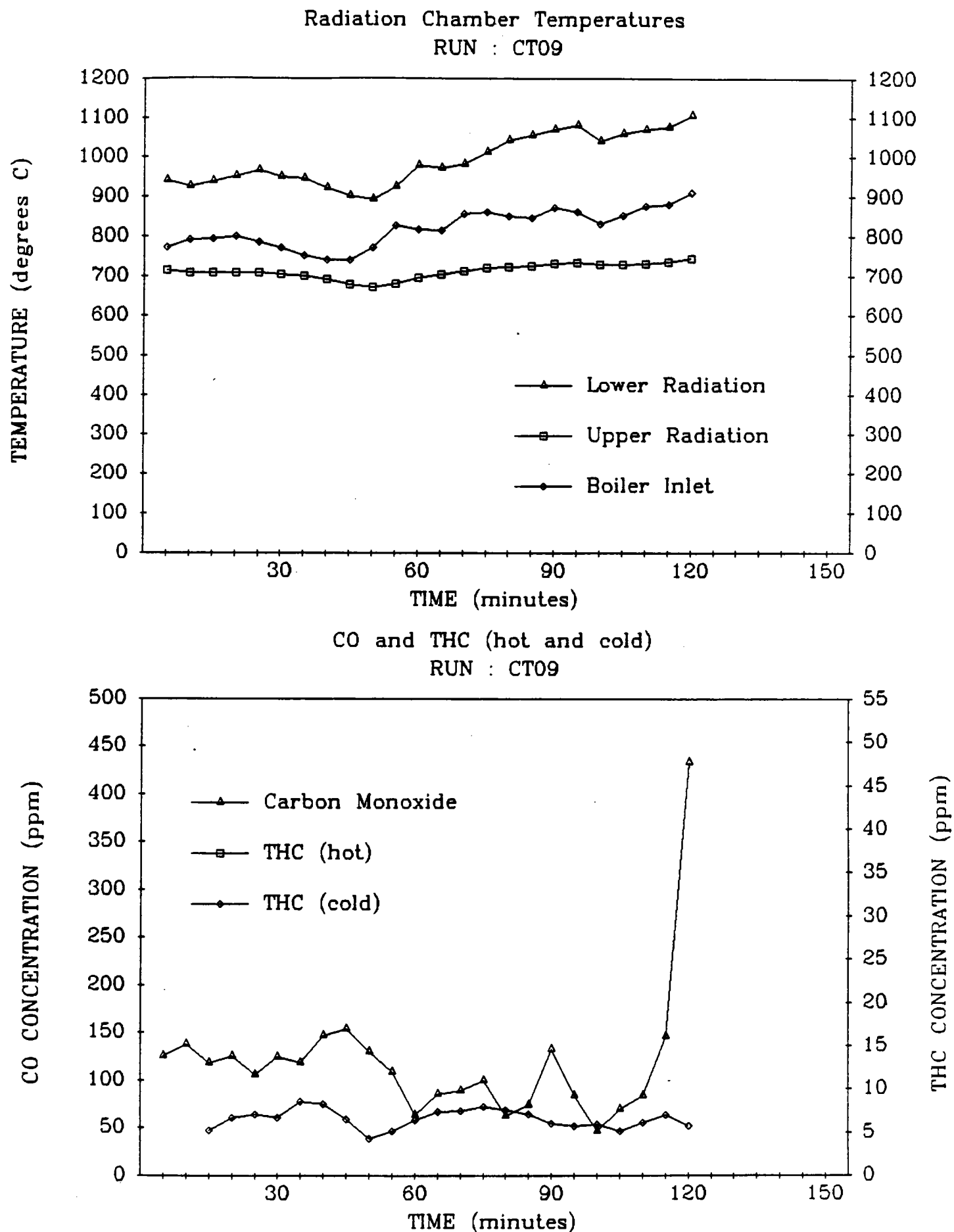
Figure 9.8 : Temperature and CO versus time - CT-15

Radiation Chamber Temperatures
RUN : CT15

CO and THC (hot and cold)
RUN : CT15

166
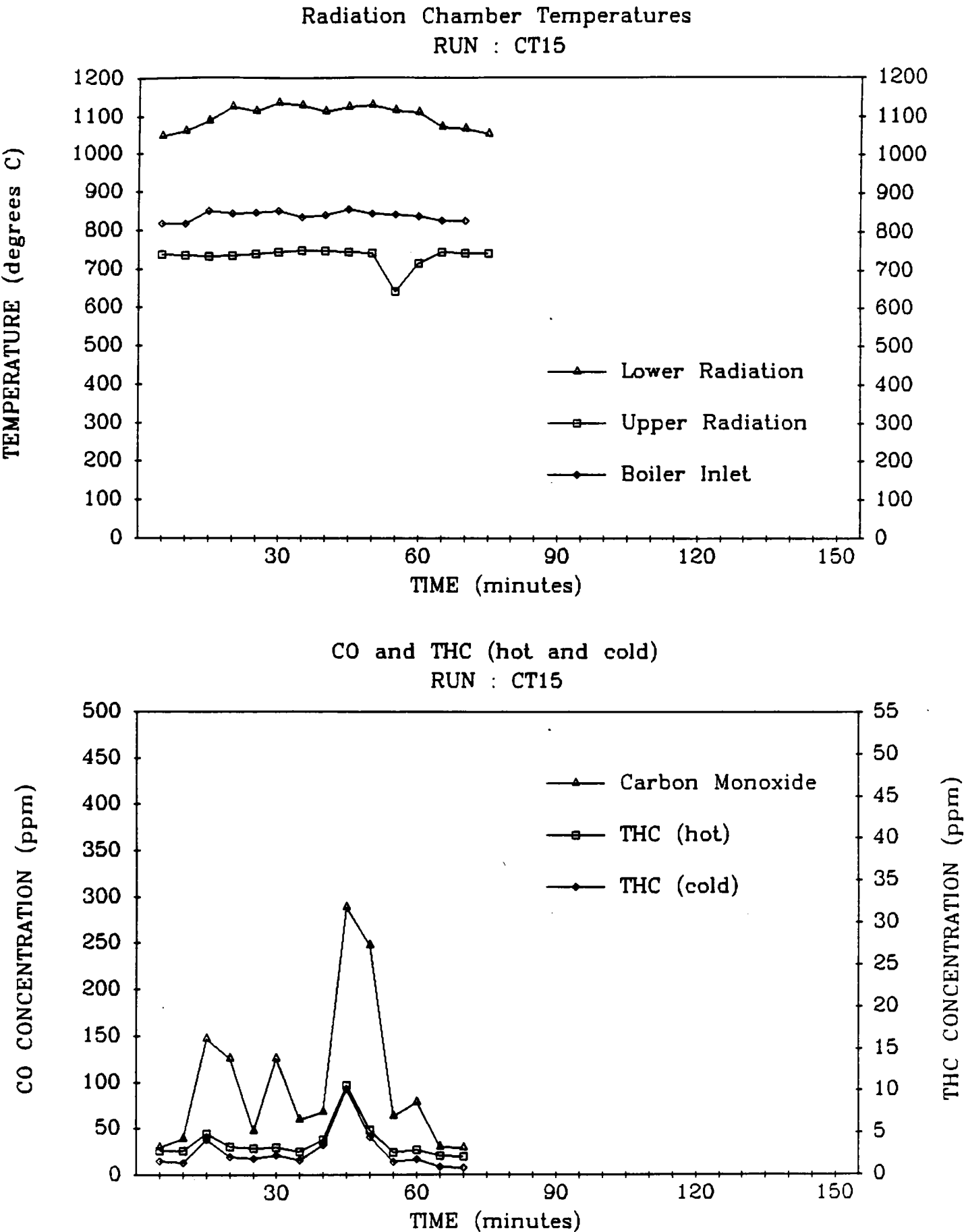
9.3.1 General Perspective on the Incineration System Performance

After extensively reviewing the results accumulated during the Characterization Test phase including visual observations, the following general assessment of the incineration system performance was developed. The conclusions provided a basis for selecting appropriate operating conditions to be Performance tested.

- The incineration system was quite capable of stable operation at all three rates tested (20, 28 and 32 t/h steam). CO levels below 100 ppm under high steam rates and below 50 ppm at low and design feed rates could be achieved.

- The primary/secondary air ratio of approximately 60:40, generally appeared to provide the most stable operation with relatively low CO concentrations. On the other hand, operation of the incinerator with minimal secondary air resulted in the highest CO rates. The significance of this primary/secondary air ratio with respect to CO levels was identified as one aspect which should be addressed by the Performance Tests.

- Control of the primary/secondary air ratio as a fixed ratio versus a variable ratio in response to the changing radiation chamber temperature (i.e. as the temperature rises the ratio decreases) showed no significant advantage one way or the other. However, with the fixed ratio control the radiation chamber temperature tended to vary more than under temperature control of the ratio. Since combustion experts and regulatory bodies emphasize temperature as one of the primary requirements for the destruction of chlorinated organics, the temperature controlled primary/secondary air ratio was chosen as the preferred operating mode for the Performance Test phase.

- When the proportion of primary air supplied in the first burning zone sections was increased as compared to Von Roll recommendations, the results included a shallower burning depth on the finishing grate zone and improved ash quality. However, increases in particulate lift-off and glowing particle carry-over into the boiler resulted. To minimize the emission rates and provide performance results that were consistent with modern Von Roll practices, the primary air distribution recommended by Von Roll was adopted as the preferred operating mode for the Performance Tests.

- The variations experienced with the secondary air distribution (i.e. front to back air supply ratio) did not seem to significantly affect the performance. With the system operating in the temperature-controlled operating mode rather than the fixed ratio mode, the front/back ratio varied automatically as the main burning zone on the grates moved forward and back. This had the effect of limiting temperature swings in the radiation chamber. This operating mode was adopted for the Performance Tests for the same reasoning outlined previously for selection of the temperature-controlled primary/secondary ratio.

- Total primary air appeared to be a critical parameter in achieving low CO levels and low particulate emission rates (i.e. very high primary air rates resulted in high CO levels and a high particulate lift-off rate). As a result, the total primary air rate was identified as a key parameter to keep under control during the Performance Test phase.

- In general, reasonable operating conditions with respect to even burning of refuse on the grates and avoidance of flame impingement on the boiler inlet tubes coincided with good primary/secondary air ratios (60:40) and low CO concentration operating conditions. Total hydrocarbon analyzer peaks usually occurred with each CO upset experienced. Since the peak

CO levels coincided with the shifts from steady operation to upset conditions, and since the CO analyzer was very reliable during the test program, CO levels were established as a key operating parameter during the Performance Tests.

- Based on the Characterization Test runs, auto control of the grate speeds in response to steam rate and oxygen levels resulted in a steady repeatable performance. When manual control was attempted, operating modes were difficult to maintain over the 2-hour test period. Auto control of the grate speeds was therefore selected for the Performance Test runs.

- During the Characterization Test runs, a wide range of excess air levels (40 to 162%) and radiation chamber temperatures (805 to 1099°C) were experienced. While other parameters seemed to have equally significant effects on the system's performance (particularly on CO levels), these two parameters were determined to be significant from the point of view of identifying and establishing a particular operating condition. Since combustion experts and regulatory bodies have emphasized specific operating temperatures as being necessary for the efficient destruction of chlorinated organics (dioxin and furans in particular), temperature was therefore determined to be the primary parameter to be used for identifying and maintaining distinctly different Performance Test conditions. In order to maintain the desired operating temperature, the excess air levels had to be adjusted as refuse quality and other operating conditions changed. For example, if refuse with a higher heating value entered the furnace, the temperature increased unless the excess air level is increased. The higher excess air level provided the additional cooling air that was required to maintain the desired radiation chamber temperature.

Considering the above perspective and the many operating modes that were tested during the Characterization Test phase, along with the limited number of tests that could be undertaken during the Performance Test Phase (16 test runs maximum), a rationale for selection of the preferred operating conditions was established.

Duplicate/Triplicate Testing

For each operating condition to be tested, replication in duplicate or triplicate was considered. The major advantage of the duplicate approach was that a greater number of operating conditions could be tested. The triplicate approach increased the statistical reliability of the data obtained. Triplicate testing was generally the preferred approach for this test program.

Operating Condition Repeatability

In addition to the duplicate/triplicate issue, there was concern that it may be difficult to repeat the conditions experienced during the relatively short duration Characterization Tests (2 hrs) throughout the longer Performance Tests (12 hrs). This concern was raised since several duplications of a particular operating condition were attempted during the CT's but were not successful. This was due to various causes such as process upsets and variations in refuse quality.

Performance Test Program Organization

It was determined that the Performance Test program should be based on testing up to five operating modes in triplicate. It was also agreed that each test condition should be first duplicated during the initial test phase. Once the duplicates were successfully completed, the third test of each operating mode could then be conducted. This approach improved the chances of at least successfully completing five operating modes in duplicate. For example, if there were initial failures to achieve the desired operating modes during the first two test runs, one or more of the planned triplicate runs could be utilized.

The completed Performance Test program consisted of three operating conditions being triplicated and two being duplicated. One test was carried out as a preliminary shakedown run at the low steam rate. Another test had to be aborted when one of the isokinetic sampling trains experienced an equipment failure. The originally proposed sixteenth test run was dropped from the program due to budget constraints.

Figure 9.9 shows the Performance Test operating conditions that were successfully completed. Table 9.5 lists each of the operating conditions selected for Performance Testing.

Table 9.5
Stratification Test Results

Test #	Ports	Flue Gas Velocity (m/s)	Deviation from Average	Particulate Loading (mg/sm^3) @12% CO$_2$	Deviation from Average %
14-1	1	16.1	13.6	78.6	9.5
14-2	2	16.3	15.0	74.3	3.5
14-3	3	12.5	11.8	66.1	7.9
14-4	4	11.8	16.8	68.2	5.0
15-1	1	14.1	28.8	42.9	20.3
15-2	2	10.9	0.5	43.9	23.1
15-3	3	10.0	8.7	25.1	29.6
15-4	4	8.8	19.6	30.7	13.9

Note: CT-14 was under high load conditions, CT-15 was under low load conditions.

Operating Condition Selection Criteria

The following briefly reviews the specific operating conditions that were tested during the Performance Test phase. Results are provided in Chapter 10.
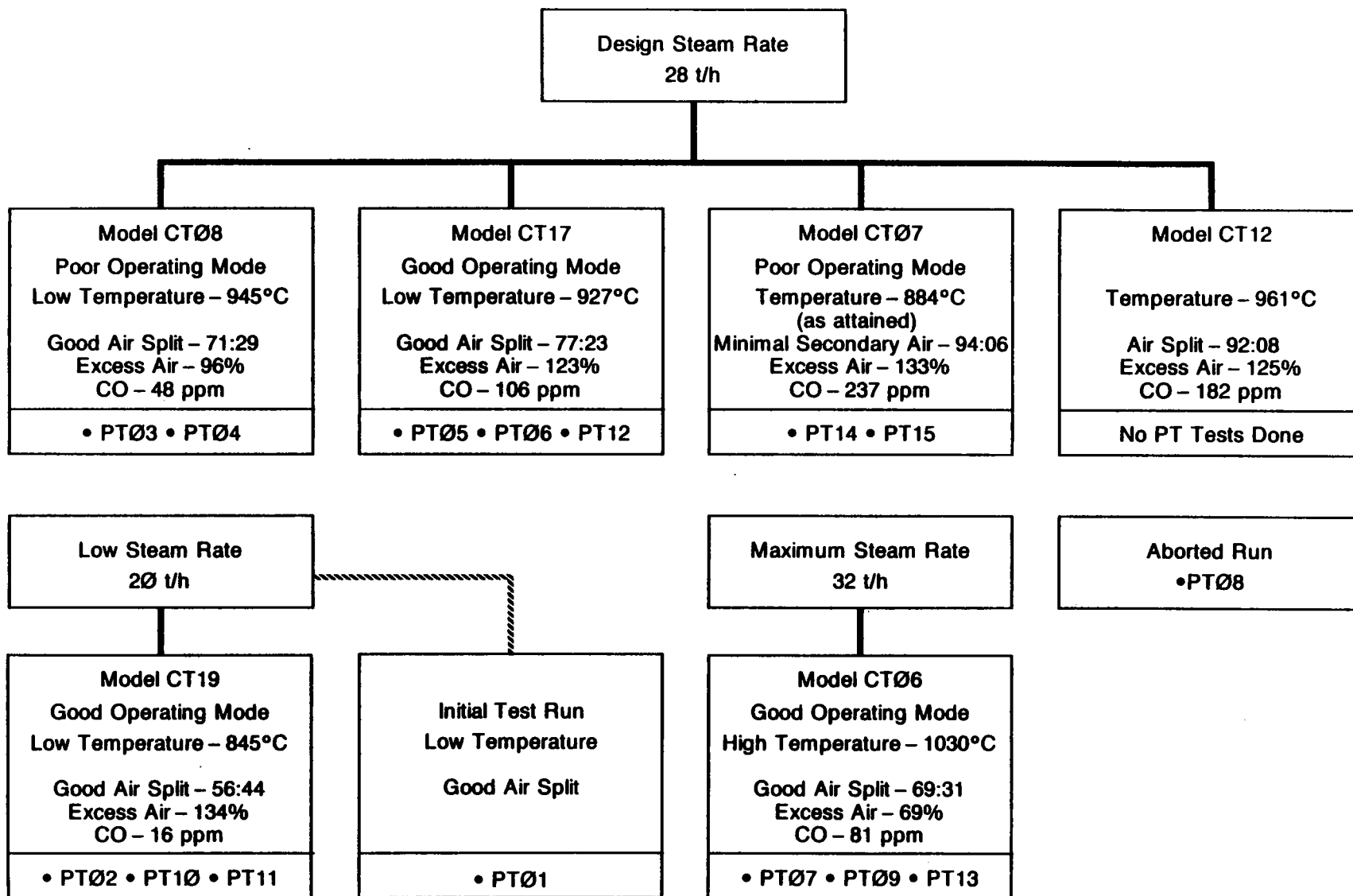
Figure 9.9
QUEBEC INCINERATOR
Performance Test Program Incinerator Operating Modes

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As indicated by Figure 9.9, three out of the five operating conditions tested were at the design steam rate. One operating condition was selected at the low steam rate and one operating condition was selected at the high steam rate. Of the three design steam rate tests, two involved potentially poor operating conditions; the third was carried out under good operating conditions. Tests at the other steam rates were carried out under good operating conditions.

Only one operating condition was selected from each of the low and high steam rate conditions since low or high feed rates do not represent the incineration system's design nor typical operating conditions. Three operating modes were selected at the design steam rate to obtain as much data for as many comparable operating conditions as budget constraints permitted. The adopted approach permitted comparison of "good" operating conditions at the design steam rate with good operating conditions at the other two steam rates. As well, comparison of good operating conditions at the design steam rate with poor operating conditions at the design steam rate was possible.

Good Operating Condition Design Steam Rate Tests

CT-08 was selected from the CT's as the basis for what could be expected during the PT's under good operating conditions. CT-08 had provided steady performance with relatively low excess air (96%), with a reasonable radiation chamber temperature (945°C), a good primary/secondary air ratio (71:29), and relatively low CO concentration (48 ppm).

It was decided that for the good operation design rate Performance Tests the target level radiation chamber temperature should be increased slightly to 1000°C. This was done so that the good operating condition burning temperatures would be consistent with the minimum operating temperatures that are being recommended by combustion experts and regulatory bodies to avoid excessive concentrations of organics. As previously indicated, review of CT-16 results led to the conclusion that low CO levels could still be expected with this increase in temperature.

Poor Operating Condition Design Steam Rate Tests

The poor operating condition design rate tests were based on the results of CT-07 and CT-17 and involved relatively high excess air levels (133 and 123% respectively). These operating conditions were expected to produce relatively high CO concentrations as compared to the good operating condition. Both represented different operating conditions.

Test CT-17 represented a relatively low operating temperature condition, the temperature experienced being below the good operating condition level of 1000°C. To ensure that the low temperature operating condition would be distinct from the "good operating" condition, it was decided that the operating temperature target should be reduced to 850°C. This change provided a more significant temperature variation (150 degrees). This poor operating mode was selected to demonstrate whether the effect of temperature on performance was significant, particularly regarding dioxin/furan flue gas concentrations.

Test CT-07 represented operation under poor combustion air distribution conditions. CT-07 was far from optimum operation, experiencing very high CO concentration of 237 ppm. This test condition is characterized primarily by the minimum secondary air rates (less than 10% of total air) and high primary air rates. While radiation chamber temperatures were relatively low (884°C) during CT-07, CT-12 experienced higher temperatures (961°C on average) with a similar primary/secondary air ratio and excess air level.

The CO concentration during CT-12 was relatively high at 182 ppm. It was decided that during Performance Testing of the poor distribution operating condition, temperature was not as critical to maintain as high excess air and minimal secondary air, thus the notation on Figure 9.9, (temperature) "as attained".

High and Low Design Steam Rate Tests

As previously indicated, one representative test was selected from each of the low and high steam rate tests. These two operating conditions were triplicated and represented good operating conditions.

CT-19 was selected as the basis for the low feed rate operating mode and CT-06 the high feed rate condition. Both of these Characterization Tests were considered since each appeared to represent optimum operation at their respective feed rates.

CT-19 with its good primary/secondary air ratio (56:44), its relatively low radiation chamber temperature (845°C), and high excess air level (135%), achieved the lowest CO levels for the program at 16 ppm at 12% CO_2.

CT-06 had a good primary/secondary air ratio (69:31), a relatively high radiation chamber temperature (1030°C), and a low excess air level (69%). CT-06 experienced the lowest CO concentrations (81 ppm) of the high steam rate tests.

9.4   RADIATION CHAMBER TEMPERATURE PROFILES (ISOTHERMS)

During the Characterization Tests, temperature measurements were taken at various locations across a horizontal plane of the furnace radiation chamber and a vertical plane at the boiler inlet. These measurements were used to develop a cross-sectional isotherm diagram illustrating equal temperature curves. The cross-section locations are described in detail in Sections 4.2 and 5.3. The temperature readings for each thermocouple were averaged over the test period for CT-01 and CT-02 to obtain the information plotted in Figures 9.10 to 9.13. Similar figures are presented in Volume IV for all of the Characterization Tests.

In general, a consistent pattern was observed in the radiation chamber for a number of the Characterization Tests. As seen in Figures 9.10 (CT-01) and 9.11 (CT-02), high temperature isotherms

Figure 9.10 : Radiation Chamber Temperature Distribution - CT-01
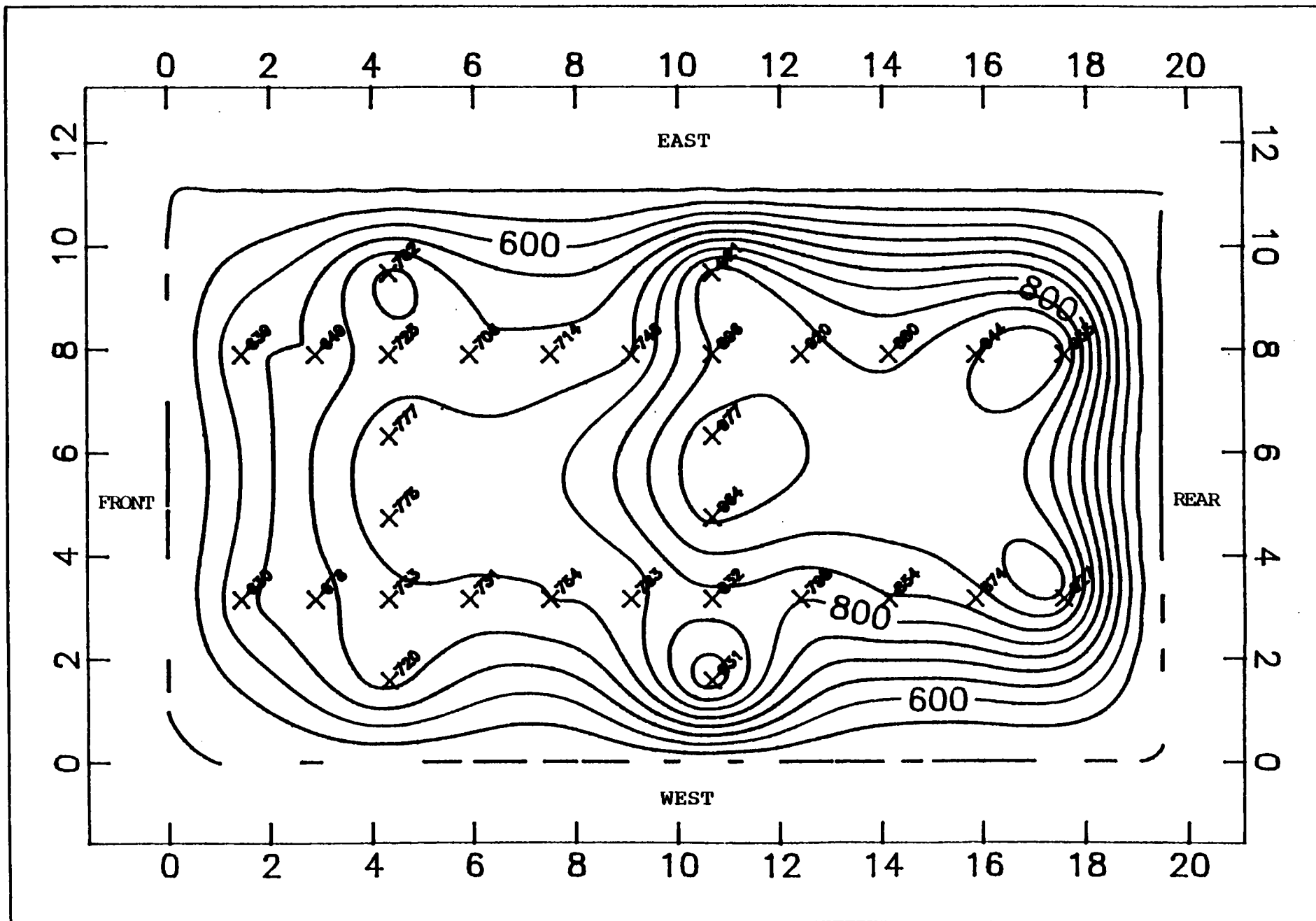
Figure 9.11 : Radiation Chamber Temperature Distribution - CT-02
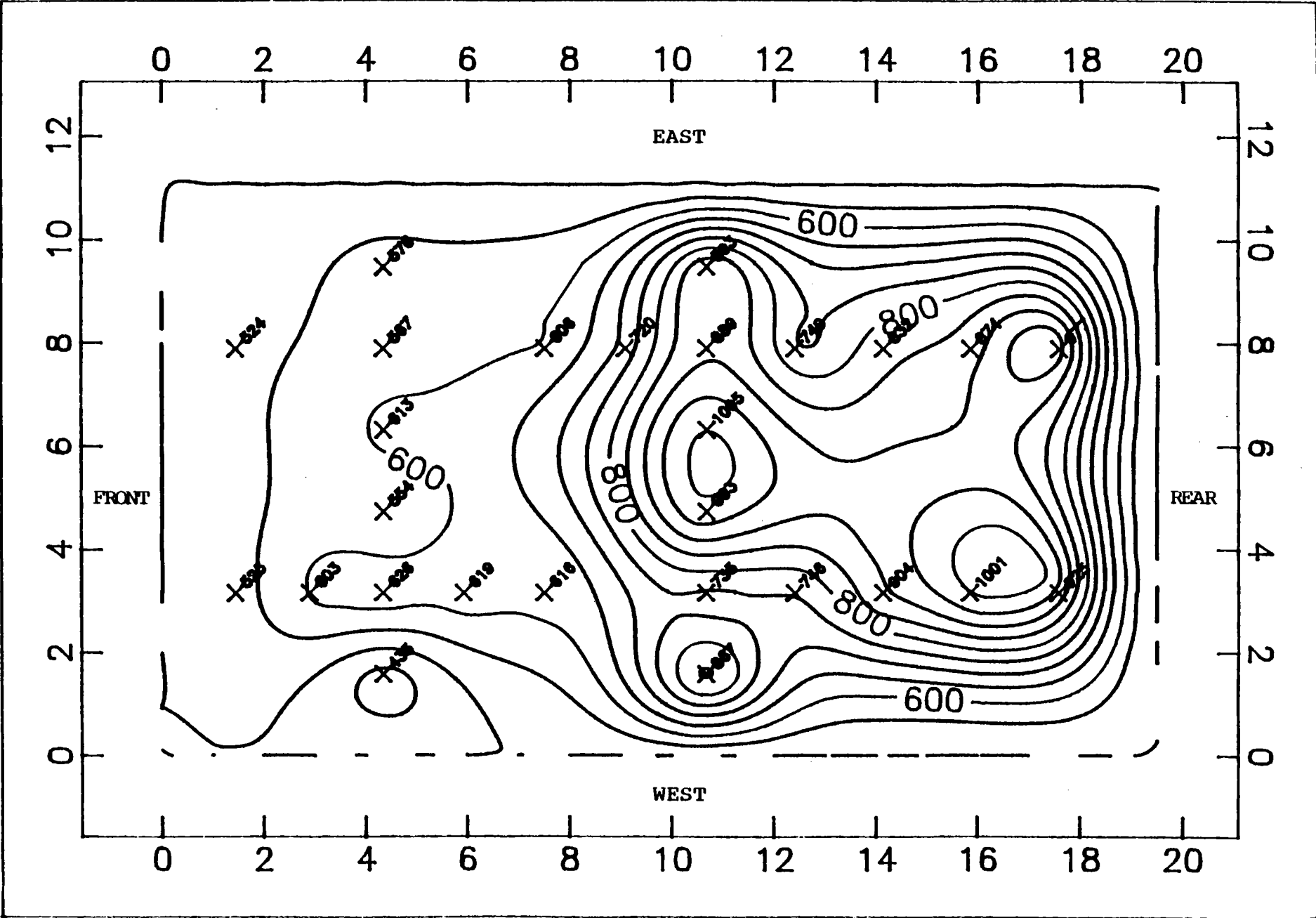
Figure 9.12 : Boiler Inlet Temperature Distribution - CT-01
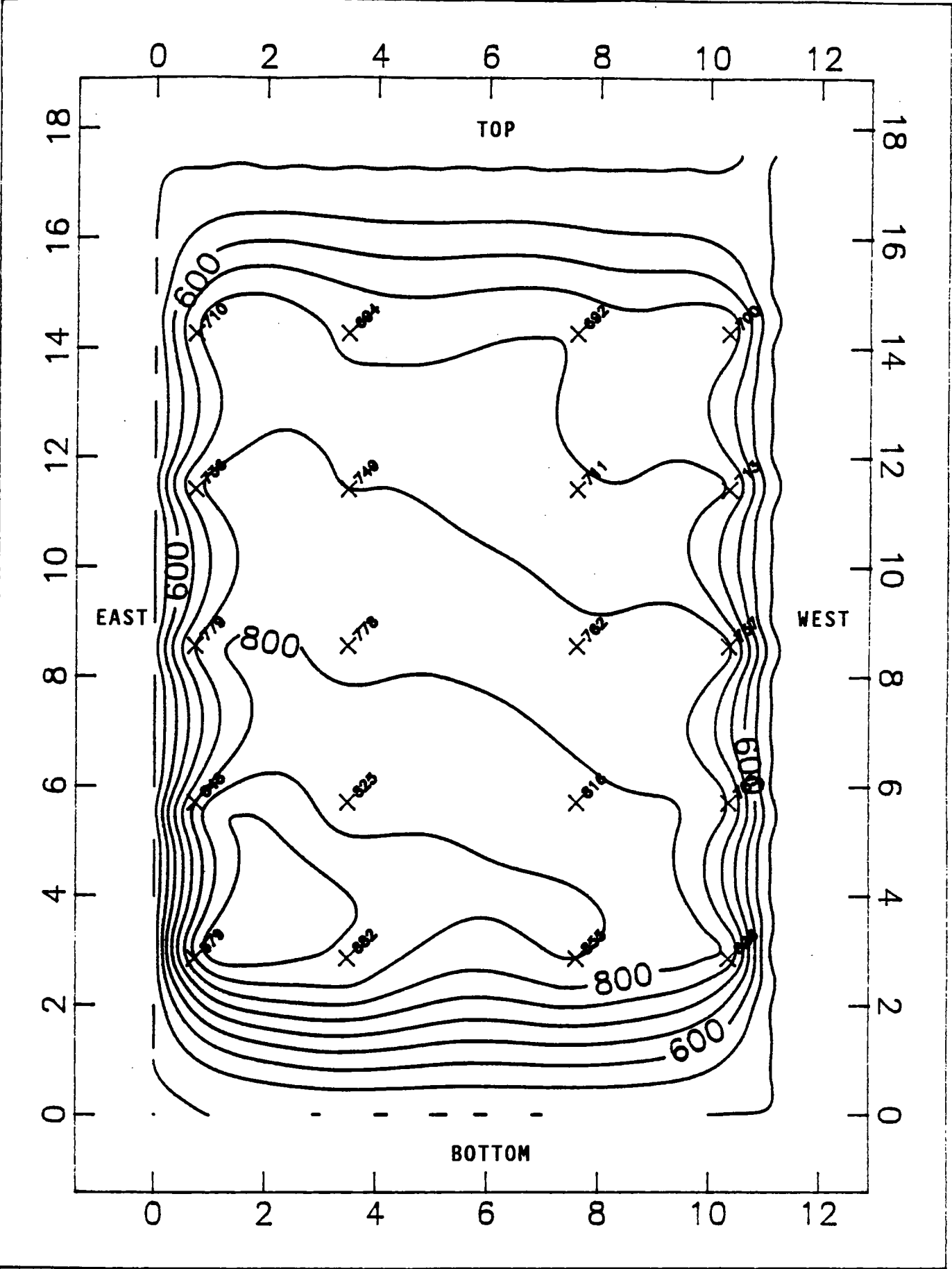
Figure 9.13 : Boiler Inlet Temperature Distribution - CT-02
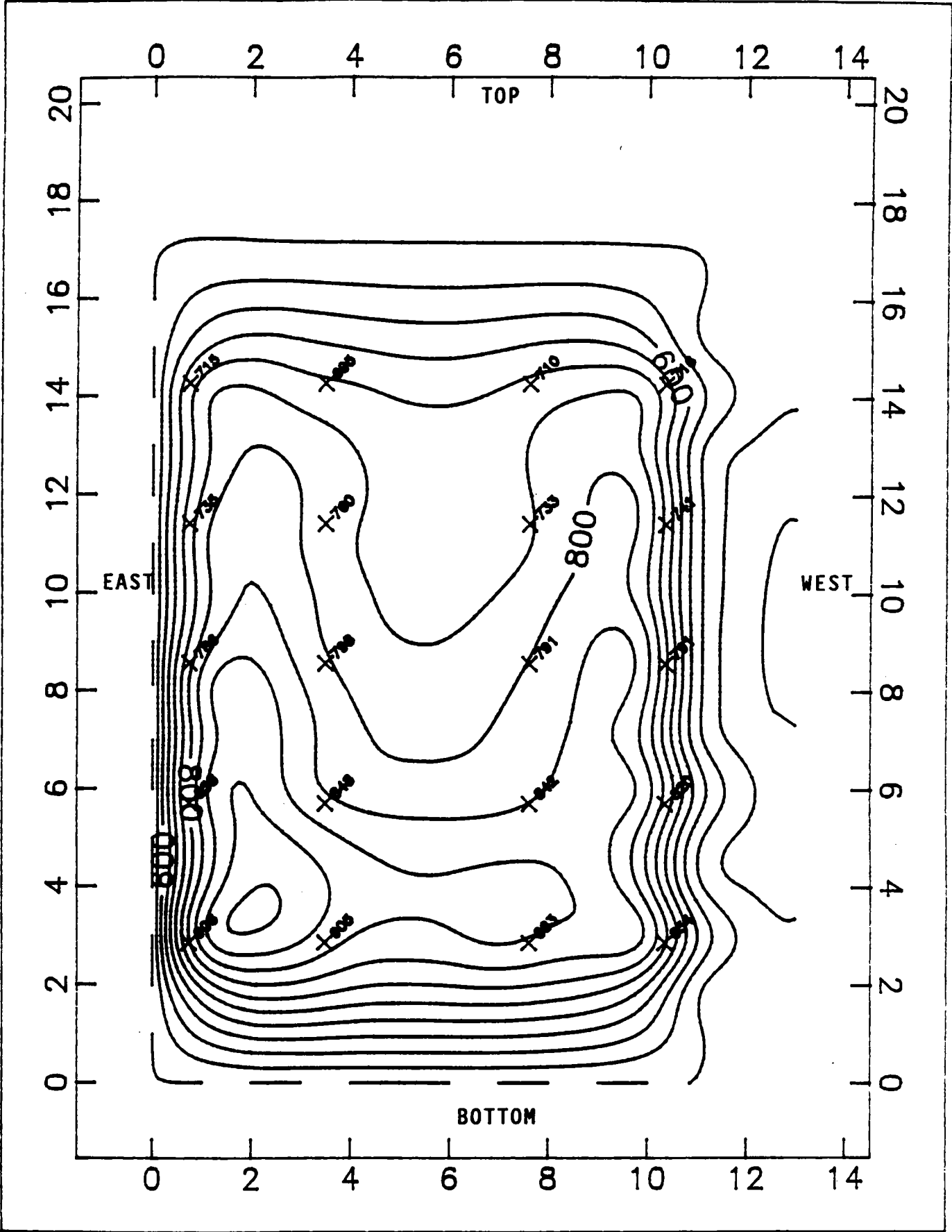
predominated near the rear bull-nose. The overfire air ratio between the front and rear did not appear to have any major effect on the temperature distribution, however the isotherms seemed to indicate that the location of the main rising flame zone was near the rear bull-nose since a low temperature zone was identified near the front wall.

Boiler inlet isotherms, Figures 9.12 (CT-01) and 9.13 (CT-02), show higher temperatures in the lower portion of the screening tube section and consistently higher temperatures at the lower east side. It is interesting to note that the secondary air supply was delivered to the radiation chamber from the east side of the furnace via a header fitted with equal diameter nozzles.

9.5   EXHAUST GAS STRATIFICATION TESTS

To assess the adequacy of the proposed flue gas sampling location prior to undertaking the Performance Tests, particulate stratification tests were carried out during CT-14 and CT-15. Four sampling trains were operated simultaneously from four ports across the horizontal duct section, to sample the particulate loading and to measure the gas velocity. The sampling methodology was described in Section 5.5.1.

Results of the stratification tests indicated that while some stratification in flue gas velocity and particulate loading was occurring in the lower part of the duct, upon close examination of the data it was agreed between Lavalin, the Scientific Authority and the Quality Control (QA/QC) Team that this location was acceptable for the Performance Test sampling in view of the low variation of the flue gas velocity and loading. A summary of the stratification test results is presented in Table 9.6.

Table 9.6
Stratification Test Results

Test #	Ports	Flue Gas Velocity (m/s)	Particulate Loading (mg/sm^3) @12% CO_2
14-1	1	16.1	78.6
14-2	2	16.3	74.3
14-3	3	12.5	66.1
14-4	4	11.8	68.2
15-1	1	14.1	42.9
15-2	2	10.9	43.9
15-3	3	10.0	25.1
15-4	4	8.8	30.7

10.0 PERFORMANCE TESTS

This chapter summarizes the scope of the Performance Test Program and presents the results. Individual test averages and replicate test averages (i.e. operating group averages) are presented in Sections 10.2 and 10.3. These sections demonstrate whether the replicate tests within each operating group are indeed replicates and whether the replicate average can be used to adequately represent results for each of the different operating conditions. A general comparison of the differences between the group averages is presented in Section 10.4. This section provides a general comparison of the differences in results between the different operating conditions. Heat recovery efficiency achieved during the program is reviewed in Section 10.5. Section 10.6 summarizes the results of the plastics separation program.

The database for this chapter is presented in Appendix A and Volume IV. A more detailed discussion of each individual test is presented in Appendix C. Reference is also made to previous chapters of this report for additional background on the approach and methodology used to obtain the results presented, and to Chapters 11 and 12 for data correlations and conclusions.

10.1 GENERAL BACKGROUND

The Performance Test phase of the program consisted of 15 test runs. Each required a full day to complete. The Performance Testing commenced on June 26 1986 and was completed by July 12, 1986. Two "break-days" were included in this period, July 1 and July 8, to enable the testing personnel to perform general maintenance on the testing equipment.

Thirteen of the fifteen Performance Test runs were completely successful. The results are presented hereafter. PT-01 was designated as being a preliminary or practice test run. This first run enabled the sampling teams and plant operators to become familiar with and responsive to the requirements of this extensive incinerator performance evaluation program. All elements of this test were completed, including laboratory analysis. PT-08 had to be aborted prior to completion when the organic sampling train glassware was accidentally broken. Accordingly, there were no to report for this test.

Test Strategy

The Performance Test conditions were selected prior to the start of the testing as discussed in Chapter 9.0. The rationale for selection of specific operating conditions was based primarily on the findings of the Characterization Testing phase. The desire to test the performance of the incinerator under three burning rates and under good as well as poor operating conditions provided the basic framework for the program. A summary of the Performance Test runs completed and their inter-relationship is illustrated in Figure 10.1.

```
                    ┌─────────────────────┐
                    │  Design Steam Rate  │
                    │       28 t/h        │
                    └─────────────────────┘
```

Design Steam Rate
28 t/h

Poor Operating Mode
Low Temperature
Good Air Split

• PTØ3 • PTØ4

Good Operating Mode
High Temperature
Good Air Split

• PTØ5 • PTØ6 • PT12

Poor Operating Mode
High Temperature
(to suit)
Minimal Secondary Air

• PT14 • PT15

Low Steam Rate
2Ø t/h

Maximum Steam Rate
32 t/h

Aborted Run
•PTØ8

Good Operating Mode
Low Temperature
Good Air Split

• PTØ2 • PT1Ø • PT11

Initial Test Run
Low Temperature
Good Air Split

• PTØ1

Good Operating Mode
High Temperature
Good Air Split

• PTØ7 • PTØ9 • PT13

Figure 10.1
QUEBEC INCINERATOR
Performance Test Program Incinerator Operating Modes

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The Performance Test schedule and the proposed or target test conditions are summarized in Table 10.1. The triplicate test runs (i.e. good operating mode conditions at the three burning rates) were scheduled so that the time between the first and third tests of each series was extended as long as the program timing permitted. This allowed time for the waste in the pit to be replaced with new and possibly different quality waste before the final triplicate test was undertaken. For example, the third low, design and high burn rate test runs were completed 9, 9 and 7 days after the first test run of each burn rate group, respectively.

TABLE 10.1
TEST SCHEDULE AND TEST CONDITION SUMMARY

Test No.	Date	Operating Mode Type	Steam Rate t/h	Lower Temp. Target °C	Combustion Air Split Primary : Secondary Target
PT-01	June 26	Prel. Test	20	850	65:35
PT-02	27	Good	20	850	65:35
PT-03	28	Poor	28	850	65:35
PT-04	29	Poor	28	850	65:35
PT-05	30	Good	28	1000	65:35
Breakday	July 01				
PT-06	02	Good	28	1000	65:35
PT-07	03	Good	32	1000	65:35
PT-08[1]	04	Good	32	1000	65:35
PT-09	05	Good	32	1000	65:35
PT-10	06	Good	20	850+	60:40
PT-11[2]	07	Good	20	850+	60:40
Breakday	08				
PT-12[3]	09	Good	28	1000	65:35
PT-13[4]	10	Good	32	1050	65:35
PT-14	11	Poor	28	to suit	90:10
PT-15	12	Poor	28	to suit	90:10

1) Test aborted, organic train failure
2) Triplicate of PT-02/10
3) Triplicate of PT-05/06
4) Triplicate of PT-07/09

In the evening before each test, the process control system was set up to achieve the desired operating condition for the next test day. This allowed the unit to stabilize at the desired operating condition overnight. Final process control adjustments were made prior to the start of each test. The adjustments followed a thorough review of the previous day's test results. Results were processed during the night shift. In addition, a visual assessment of the furnace conditions by the combustion experts was carried out prior to the start of testing to ensure that the system was operating satisfactorily at the selected operating condition.

Summary of Results

Tables 10.2A and 10.2B summarize some of the results of the successfully completed Performance Tests. To assist in comparing replicate tests, Tables 10.2C and 10.2D present these same results with replicate tests (i.e. operating modes) grouped together. As detailed in Section 10.2.3, PT-13 is not shown in Tables 10.2C and 10.2D, because it was not considered as a duplicate or triplicate of the other tests. Other results obtained are presented in the following sub-sections, such as particle size analysis, heavy metals and organics content of the flue gas, refuse and ash samples. With the exception of the laboratory-based results, the partially "reduced" data presentation in Tables 10.2C and 10.2D were available the morning after each test. This summary was reviewed by the testing team prior to the start of the next test to ensure that program goals were being achieved.

The data presented in this chapter are based on test run averages. The continuously monitored process parameters and continuous gas analyzer results presented include only the data generated for the time periods when manual stack sampling trains were in operation.

Test Averages vs Short-Term Averages

The actual real-time values of most measured process parameters and flue gas monitors varied more than is apparent from the test average data. For example, Figure 10.2 shows the typical variation of carbon monoxide concentration on a 5-minute averaging time basis for good (PT-05) and poor (PT-15) operating conditions. In both instances, peaks were about three times the average, however for the good test, carbon monoxide concentrations were much more stable than was the case for the poor test operating condition. Other test results are presented in Appendix A and Volume IV, in tabular form and graphic form on the 5-minute average basis.

Figure 10.3 shows the 30 second reading and corresponding averages experienced during one hour of PT-15.

In Appendix C of this report, some of the factors that cause the short-term variations are discussed. Since many of the test results are only available on the test average basis (i.e. particulates, dioxins, furans, heavy metals, etc.), only test average data are addressed in subsequent sections of this report.

Test Conditions Limits

To ensure that the distinctly different operating conditions as proposed in Table 10.1 were achieved, acceptable levels of variation for several process control parameters were established, based on experience obtained during the Characterization Tests. These limits were set to ensure that the desired operating condition was achieved and maintained throughout the test. This placing of limits on the variation experienced within each operating condition offered the greatest potential for:

● making meaningful comparisons between the distinctly different operating conditions, and

● obtaining correlations between specific emissions and process parameters.

TABLE 10.2A
NITEP - QUEBEC
PERFORMANCE TEST RUN PROCESS AVERAGE VALUES

PERFORMANCE TEST #:		PT01	PT02	PT03	PT04	PT05	PT06	PT07	PT09	PT10	PT11	PT12	PT13	PT14	PT15
OPERATION CONDITION:		PRELIM.	GOOD	POOR	POOR	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	POOR	POOR
FEED RATE:		LOW	LOW	DESIGN	DESIGN	DESIGN	DESIGN	HIGH	HIGH	LOW	LOW	DESIGN	HIGH	DESIGN	DESIGN
Steam Rate (Tonnes/hr)	tonne/hr	20.1	20.0	28.1	27.8	28.0	28.1	31.8	31.8	20.0	20.0	27.9	31.6	28.4	28.3
Refuse Feed Rate (wet)	tonne/hr	6.8	6.2	10.1	9.0	8.7	8.7	8.6	10.8	6.5	6.7	9.3	11.3	8.4	9.0
Steaming Ratio (TonneSt/TonneRef)		3.0	3.2	2.8	3.1	3.2	3.2	3.7	2.9	3.1	3.0	3.0	2.8	3.4	3.1
Moisture in Refuse	%	27.4	38.6	32.2	36.3	36.8	38.3	32.3	37.2	32.9	39.3	30.9	37.2	31.2	35.1
Moisture in Flue Gas	% by VOL	11.6	13.4	14.1	13.1	15.8	16.4	13.8	16.1	11.9	13.3	14.7	15.2	12.5	14.1
Combustion Efficiency	%	99.92	99.99	99.94	99.93	99.98	99.98	99.96	99.96	99.98	99.98	99.97	99.94	99.87	99.86
Input/Output Efficiency	%	58.4	62.4	60.5	59.7	67.3	60.5	67.9	64.4	60.5	62.0	63.3	58.8	64.8	61.8
Incinerator Ash Rate (dry)	kg/h	2675	1156	2749	2306	2311	2717	1888	2324	2365	1414	2210	2862	1797	2360
Percent Refuse Input	%	39.3	18.6	27.2	25.6	26.6	31.2	22.0	21.5	36.4	21.1	23.7	25.3	21.4	26.3
Percent Combustibles	%	6.8	4.0	2.3	6.0	1.5	11.9	7.5	2.8	3.3	0.6	4.1	14.6	1.9	6.4
Boiler Ash Rate (dry)	kg/h	20.2	29.4	30.7	38.4	33.5	24.4	41.5	58.9	36.6	33.3	44.0	62.0	57.3	42.9
Percent Refuse Input	%	0.3	0.5	0.3	0.4	0.4	0.3	0.5	0.5	0.6	0.5	0.5	0.5	0.7	0.5
Percent Combustibles	%	4.8	5.9	10.0	10.1	15.5	7.2	21.9	23.7	5.9	2.3	1.3	1.3	3.0	5.3
Precipitator Ash Rate (dry)	kg/h	35.6	46.0	131.6	131.0	47.0	54.2	65.8	92.4	46.6	43.5	71.0	128.4	121.8	110.8
Percent Refuse Input	%	0.5	0.7	1.3	1.5	0.5	0.6	0.8	0.9	0.7	0.6	0.8	1.1	1.5	1.2
Percent Combustibles	%	7.9	7.2	5.8	6.3	8.0	36.9	11.8	9.4	4.8	8.6	7.1	7.4	10.5	6.0
Flue Gas Flow (Average of 3 Trains)	Sm3/min	960	874	1130	1156	828	844	945	985	910	875	953	1036	1055	1046
Total Comb. Air (Bailey)	Am3/min	525	477	918	960	546	541	625	750	553	498	550	725	540	555
Combustion Air Distribution:															
-Primary Secondary Ratio		23:77	58:42	61:39	61:39	65:35	64:36	49:51	60:40	53:47	63:37	66:34	63:37	88:12	89:11
-Secondary Front/Rear Ratio		57:43	42:58	47:53	50:50	39:61	31:69	60:40	64:36	56:44	44:56	42:58	64:36	27:73	25:75
Temperatures (deg C) :															
-Lower Radiation Chamber [F/R avg]	C	842	849	861	856	1014	1030	1085	1006	875	869	992	997	992	964
-Upper Radiation Chamber [F/R avg]	C	618	637	672	655	777	774	839	791	688	688	793	799	747	718
-Boiler Inlet	C	698	712	724	700	813	817	836	809	688	689	785	769	745	762
-Stack	C	202	199	229	232	206	212	220	233	212	212	225	240	232	228

TABLE 10.2B
NITEP - QUEBEC
PERFORMANCE TEST RUN PROCESS AVERAGE VALUES

PERFORMANCE TEST #:		PT01	PT02	PT03	PT04	PT05	PT06	PT07	PT09	PT10	PT11	PT12	PT13	PT14	PT15
OPERATION CONDITION:		PRELIM.	GOOD	POOR	POOR	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	POOR	POOR
FEED RATE:		LOW	LOW	DESIGN	DESIGN	DESIGN	DESIGN	HIGH	HIGH	LOW	LOW	DESIGN	HIGH	DESIGN	DESIGN
Continuous Flue Gas Data [corr.to 12% CO2]:															
Carbon Dioxide	%	8	8	9	8	11	11	10	11	8	8	9	10	8	9
Carbon Monoxide	ppm	92	17	76	80	20	27	43	43	24	30	37	77	153	173
Oxygen (dry basis)	%	13	13	12	12	9	9	10	10	13	12	10	10	12	11
THC cold	ppm	6	2	2	2	1	2	2	2	3	2	2	2	3	3
THC hot	ppm	8	6	3	6	NA	NA	NA	NA	4	5	4	NA	NA	2
SO2	ppm	203	160	145	160	178	186	192	128	209	175	225	178	162	151
NOX	ppm	207	232	224	246	172	169	186	202	191	192	199	205	191	183
HCL	ppm	384	565	NA	453	504	366	512	369	465	466	487	500	594	447
Excess Air	%	146	143	128	132	69	75	84	84	152	126	91	92	116	110
Opacity	%	29	26	35	36	32	29	35	30	31	30	39	36	36	35
Particulate Sampling Train															
- Concentration @ 12% CO2	mg/Sm3	51.4	23.7	68.1	41.7	15.8	20.5	35.3	35.9	28.9	26.3	30.7	53.7	72.9	52.0
- Emission Rate/Refuse Ratio	kg/tonne	0.3	0.1	0.3	0.2	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.2	0.4	0.3
Hydrogen Chloride Sampling Train															
- Concentration @ 12% CO2	ppm	319	612	601	327	327	312	364	397	463	440	450	449	398	398
- Emission Rate/Refuse Ratio	kg/tonne	2.8	5.4	5.0	3.2	3.0	2.9	3.4	3.3	4.3	3.8	3.7	3.7	4.2	3.9
Total PCDD (Organic Sampling Train)															
- Concentration @ 12% CO2	ng/Sm3	574	105	302	295	13	11	45	65	29	24	33	164	205	233
- Emission Rate/Refuse Ratio	ug/tonne	3085	559	1444	1486	68	59	256	312	151	122	154	736	1065	1195
Total PCDF (Organic Sampling Train)															
- Concentration @ 12% CO2	ng/Sm3	575	179	287	310	49	32	101	100	81	84	52	118	336	277
- Emission Rate/Refuse Ratio	ug/tonne	3086	950	1369	1565	261	171	570	480	429	423	247	532	1747	1421

TABLE 10.2C

NITEP - QUEBEC

PERFORMANCE TEST RUN PROCESS AVERAGE VALUES

PERFORMANCE TEST #:		PT02	PT10	PT11	PT05	PT06	PT12	PT07	PT09	PT03	PT04	PT14	PT15
OPERATION CONDITION:		GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	POOR	POOR	POOR	POOR
FEED RATE:		LOW	LOW	LOW	DESIGN	DESIGN	DESIGN	HIGH	HIGH	DESIGN	DESIGN	DESIGN	DESIGN
										LOW TEMPERATURE		POOR AIR DISTN.	
Steam Rate (Tonnes/hr)	tonne/hr	20.0	20.0	20.0	28.0	28.1	27.9	31.8	31.8	28.1	27.8	28.4	28.3
Refuse Feed Rate (wet)	tonne/hr	6.2	6.5	6.7	8.7	8.7	9.3	8.6	10.8	10.1	9.0	8.4	9.0
Steaming Ratio (TonneSt/TonneRef)		3.2	3.1	3.0	3.2	3.2	3.0	3.7	2.9	2.8	3.1	3.4	3.1
Moisture in Refuse	%	38.6	32.9	39.3	36.8	38.3	30.9	32.3	37.2	32.2	36.3	31.2	35.1
Moisture in Flue Gas	% by VOL	13.4	11.9	13.3	15.8	16.4	14.7	13.8	16.1	14.1	13.1	12.5	14.1
Combustion Efficiency	%	99.99	99.98	99.98	99.98	99.98	99.97	99.96	99.96	99.94	99.93	99.87	99.86
Input/Output Efficiency	%	62.4	60.5	62.0	67.3	60.5	63.3	67.9	64.4	60.5	59.7	64.8	61.8
Incinerator Ash Rate (dry)	kg/h	1156	2365	1414	2311	2717	2210	1888	2324	2749	2306	1797	2360
Percent Refuse Input	%	18.6	36.4	21.1	26.6	31.2	23.7	22.0	21.5	27.2	25.6	21.4	26.3
Percent Combustibles	%	4.0	3.3	0.6	1.5	11.9	4.1	7.5	2.8	2.3	6.0	1.9	6.4
Boiler Ash Rate (dry)	kg/h	29.4	36.6	33.3	33.5	24.4	44.0	41.5	58.9	30.7	38.4	57.3	42.9
Percent Refuse Input	%	0.5	0.6	0.5	0.4	0.3	0.5	0.5	0.5	0.3	0.4	0.7	0.5
Percent Combustibles	%	5.9	5.9	2.3	15.5	7.2	1.3	21.9	23.7	10.0	10.1	3.0	5.3
Precipitator Ash Rate (dry)	kg/h	46.0	46.6	43.5	47.0	54.2	71.0	65.8	92.4	131.6	131.0	121.8	110.8
Percent Refuse Input	%	0.7	0.7	0.6	0.5	0.6	0.8	0.8	0.9	1.3	1.5	1.5	1.2
Percent Combustibles	%	7.2	4.8	8.6	8.0	36.9	7.1	11.8	9.4	5.8	6.3	10.5	6.0
Flue Gas Flow (Average of 3 Trains)	Sm3/min	874	910	875	828	844	953	945	985	1130	1156	1055	1046
Total Comb. Air (Bailey)	Am3/min	477	553	498	546	541	550	625	750	918	960	540	555
Combustion Air Distribution:													
-Primary Secondary Ratio		58:42	53:47	63:37	65:35	64:36	66:34	49:51	60:40	61:39	61:39	88:12	89:11
-Secondary Front/Rear Ratio		42:58	56:44	44:56	39:61	31:69	42:58	60:40	64:36	47:53	50:50	27:73	25:75
Temperatures (deg C) :													
-Lower Radiation Chamber [F/R avg]	C	849	875	869	1014	1030	992	1085	1006	861	856	992	964
-Upper Radiation Chamber [F/R avg]	C	637	688	688	777	774	793	839	791	672	655	747	718
-Boiler Inlet	C	712	688	689	813	817	785	836	809	724	700	745	762
-Stack	C	199	212	212	206	212	225	220	233	229	232	232	228

TABLE 10.20
NITEP - QUEBEC
PERFORMANCE TEST RUN PROCESS AVERAGE VALUES

PERFORMANCE TEST #:		PT02	PT10	PT11	PT05	PT06	PT12	PT07	PT09	PT03	PT04	PT14	PT15
OPERATION CONDITION:		GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	POOR	POOR	POOR	POOR
FEED RATE:		LOW	LOW	LOW	DESIGN	DESIGN	DESIGN	HIGH	HIGH	DESIGN	DESIGN	DESIGN	DESIGN
Continuous Flue Gas Data [corr.to 12% CO2]:													
Carbon Dioxide	%	8	8	8	11	11	9	10	11	9	8	8	9
Carbon Monoxide	ppm	17	24	30	20	27	37	43	43	76	80	153	173
Oxygen (dry basis)	%	13	13	12	9	9	10	10	10	12	12	12	11
THC cold	ppm	2	3	2	1	2	2	2	2	2	2	3	3
THC hot	ppm	6	4	5	NA	NA	4	NA	NA	3	6	NA	2
SO2	ppm	160	209	175	178	186	225	192	128	145	160	162	151
NOX	ppm	232	191	192	172	169	199	186	202	224	246	191	183
HCL	ppm	565	465	466	504	366	487	512	369	NA	453	594	447
Excess Air	%	143	152	126	69	75	91	84	84	128	132	116	110
Opacity	%	26	31	30	32	29	39	35	30	35	36	36	35
Particulate Sampling Train													
- Concentration @ 12% CO2	mg/Sm3	23.7	28.9	26.3	15.8	20.5	30.7	35.3	35.9	68.1	41.7	72.9	52.0
- Emission Rate/Refuse Ratio	kg/tonne	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.2	0.4	0.3
Hydrogen Chloride Sampling Train													
- Concentration @ 12% CO2	ppm	612	463	440	327	312	450	364	397	601	327	398	398
- Emission Rate/Refuse Ratio	kg/tonne	5.4	4.3	3.8	3.0	2.9	3.7	3.4	3.3	5.0	3.2	4.2	3.9
			4.5			*3.2*			*.4*		*2.1*		*7.1*
Total PCDD (Organic Sampling Train)													
- Concentration @ 12% CO2	ng/Sm3	105	29	24	13	11	33	45	65	302	295	205	233
- Emission Rate/Refuse Ratio	ug/tonne	559	151	122	68	59	154	256	312	1444	1486	1065	1195
			~78			*94*		*284*		*1465*		*1130*	
Total PCDF (Organic Sampling Train)													
- Concentration @ 12% CO2	ng/Sm3	179	81	84	49	32	52	101	100	287	310	336	277
- Emission Rate/Refuse Ratio	ug/tonne	950	429	423	261	171	247	570	480	1369	1565	1747	1421
			600			*226*		*525*		*1467*		*1584*	

The process control parameters and limits established were as follows:

- Steam rate variation not greater than ±10% of the set-point;

- Incineration Combustion Chamber Temperature ± 30 Celsius degrees of the desired level; and

- Occurrence of Abnormal Peaks of Carbon Monoxide Concentration. If such peaks extended beyond a 5-minute duration, they were evaluated as representing unusual upset conditions.

It was determined from Characterization Test experience, that conditions outside the above limits were due to system upsets. The combustion experts and the Scientific Authority agreed that if testing continued during such upset conditions, the possibility of duplicating or triplicating the desired operating conditions would be jeopardized. It was also agreed that such upsets would virtually eliminate the possibility of correlation of the emission and process parameter data. Therefore, during an upset, the sampling train probes were removed from the stack and the test interrupted or the start of the traverse delayed until the effects of the upset had passed. Interruption of sampling during the traverse occurred during six tests (i.e. PT-02, PT-06, PT-07, PT-13, PT-14 and PT-15) as shown in the following table. The reason and possible cause for the interruption in each case is also described.

Test Interruption Episodes

Test Run	Reason for Interruption	Possible Cause of Upset
PT-02	Several CO peaks occurred. One such peak was of sufficient duration to require the probes to be pulled.	Excessive steam pressure variations and/or wet refuse.
PT-06	One CO peak was abnormal and the probes were pulled.	Excessive steam pressure variations.
PT-07	One CO peak was abnormal and the probes were pulled.	Rapid reduction of excess air level; volatile refuse.
PT-13	Two abnormal CO peaks occurred and probes were pulled both times.	Low radiation chamber temperature and high primary air rate; wet refuse
PT-14	One abnormal CO peak occurred and probes were pulled.	Excessively uneven burning bed depth due to slag restritions.
PT-15	Two excessively low steam rate periods occurred and probes were pulled both times.	Slag restrictions.

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Traverses were delayed during PT-05 and PT-06. The cause of each interruption is discussed in Appendix C of this report.

10.2 REVIEW OF RESULTS BY TEST GROUP

This section presents and discusses the differences in the results that were experienced between tests within each of the three good operating mode test groups.

The differences in the results for the design steam rate at a poor operating mode are presented in Section 10.3. Section 10.3 also compares the two poor operating mode test group averages with the design rate and good operating mode tested.

Good operating conditions were defined as steady and normal operation with low CO emissions (i.e. less than 100 ppm with minimum occurrence of peaks) and good primary/secondary air distribution (65:35). Also, with the exception of the low steam rate operation (i.e. significant reduction in operating temperature due to the waterwall), radiation chamber temperatures above 950°C were also equated with good operating conditions for design and high rate test conditions, above 850°C for low rate operation.

Low, design and high burning rates were defined as 20, 28 and 32 tonnes of steam produced per hour, respectively.

10.2.1 Good Operating Conditions at Low Burning Rate

Three tests (PT-02, PT-10 and PT-11) were successfully completed with the incinerator operating at the low burning rate of 20 t/h steam (70% of the design rate) and under relatively good operating conditions.

Figure 10.4 summarizes the results of this test group. Values presented are the average of the three tests. These average values are considered to be representative of incinerator performance under low burning rate and good operating conditions, since no significant deviations in operating conditions between replicate tests occurred. The following reviews specific process parameters and sampling program results that support this conclusion.

Process Parameter Results

Reference is made to the process parameters summary, Table 10.3.

OPERATING CONDITIONS

STEAM		
- FLOW	20	tonne/h
- PRESSSURE	4291	kPa
- TEMPERATURE	322	°C

TEMPERATURES		
- LOWER INCINERATOR	864	°C
- UPPER INCINERATOR	671	°C
- BOILER INLET	696	°C
- COMBUSTION AIR	31.6	°C

AIR FLOW			RATIO
- COMBUSTION	509	Am³/min	
- PRIMARY	296	Am³/min	58 %
- SECONDARY	213	Am³/min	42 %

EFFICIENCY		
- INPUT/OUTPUT	61.6	%

STACK EMISSIONS

GAS		
- FLOW	561	Sm³/min
- TEMPERATURE	208	°C
- MOISTURE	12.9	%
- OPACITY	29.0	%

CONTINUOUS DATA		
- O_2	13	%
- CO_2	8	%
- CO	23	ppm
- NO_x	205	ppm
- SO_2	181	ppm
- THC	2	ppm

ACID GAS		
- HCl	499	ppm

ORGANIC ANALYSIS		
- PCDD	53	ng/Sm³*
- PCDF	114	ng/Sm³*
- PCB	4281	ng/Sm³*
- PAH	7090	ng/Sm³*
- CB	3497	ng/Sm³*
- CP	9492	ng/Sm³*

PARTICULATE		
	26	mg/Sm³*

METALS		
- Cd	26.4	ug/Sm³*
- Pb	978	ug/Sm³*
- Cr	10.6	ug/Sm³*
- Ni	8.9	ug/Sm³*
- Hg	783	ug/Sm³*
- Sb	35.2	ug/Sm³*
- As	1.5	ug/Sm³*
- Cu	39.4	ug/Sm³*
- Zn	1619	ug/Sm³*

* Corrected to 12% CO_2

REFUSE

FEED RATE	6.5	tonne/hr
MOISTURE	37	%
CALORIFIC VALUE	2907	cal/g

ORGANIC ANALYSIS		
- PCDD	7.8	mg/tonne
- PCDF	ND	mg/tonne
- PCB	55	mg/tonne
- PAH	4720	mg/tonne
- CB	22	mg/tonne
- CP	606	mg/tonne

METALS		
- Cd	2.9	g/tonne
- Pb	120	g/tonne
- Cr	53.5	g/tonne
- Ni	23.4	g/tonne
- Hg	.56	g/tonne
- Sb	2.9	g/tonne
- As	1.0	g/tonne
- Cu	386	g/tonne
- Zn	194	g/tonne

ASH

	INCINERATOR	BOILER	PRECIPITATOR	
ASH RATE	1645	33	45	Kg/h
ORGANIC ANALYSIS				
- PCDD	.11	135	757	ng/g
- PCDF	.12	122	219	ng/g
- PCB	ND	ND	5	ng/g
- PAH	153	71	101	ng/g
- CB	16	1567	963	ng/g
- CP	10	112	1242	ng/g
METALS				
- Cd	3.4	286	877	ug/g
- Pb	766	9323	20667	ug/g
- Cr	230	331	454	ug/g
- Ni	102	111	100	ug/g
- Hg	.0027	8.3	49	ug/g
- Sb	12	342	553	ug/g
- As	7.7	83	133	ug/g
- Cu	1773	636	1323	ug/g
- Zn	2307	17600	60900	ug/g

FIGURE 10.4
GOOD OPERATING CONDITIONS, LOW BURNING RATE
PERFORMANCE TEST SUMMARY — PT02/10/11

Table 10.3
Process Parameters under Good Operating
Conditions at Low Burning Rate.

	PT-02	PT-10	PT-11	Group Average
Steam Rate (tonne/hr)	20	20	20	20
Primary Air (% of total)	58	53	63	58
Secondary Air (% of total)	42	47	37	42
Radiation Chamber Temp. ($^{\circ}$C)	849	875	869	864
Boiler Inlet Temp. ($^{\circ}$C)	712	688	689	696
Excess Air Level (%)	143	152	126	140
Input/Output Efficiency (%)	62.4	60.5	62.0	61.6
Steaming Ratio (kgs/kgr)	3.2	3.1	3.0	3.1
Flue Gas Flow Rate (Sm^3/min)	874	910	875	886

The **steam rate** average was the same for all three tests (20 t/h).

The **primary/secondary air ratio** was within the range considered necessary to achieve good combustion (58:42 on average). Variation of this ratio between the three tests was relatively high compared to the variation experienced during good operating conditions at the design burning rate.

The **radiation chamber temperatures** were fairly consistent between these tests (i.e. 26 C degrees between the maximum and minimum test run) and were within 14 C degrees of the target set-point of 850°C (on average). The radiation chamber temperatures were relatively low compared to the temperatures experienced during the higher steam rates and under good operating conditions.

Excess air levels were similar for the three tests (i.e. within 11% of the group average). The excess air levels were considerably higher than the levels experienced during the higher steam rates and under good operating conditions.

The **heat recovery efficiency** and **steaming ratio** were consistent between the three tests, all being within 3% of the group average.

The **flue gas** flow rate was also consistent between the three tests, all tests being within 3% of the group average.

Continuous Gas Results

The **continuous flue gas** monitoring data for the test group are summarized in Table 10.4.

Table 10.4
Continuous Gas Data Under Good Operating
Conditions and Low Burning Rate

	PT-02	PT-10	PT-11	Group Average
Carbon Monoxide (ppm)	16.5	24.2	29.7	23.5
Total hydrocarbons cold (ppm)	2.3	2.5	2.2	2.3
hot (ppm)	6.0	4.0	5.3	5.1
Nitrogen oxides (ppm)	232	191	192	205
Hydrogen chloride (ppm)	565	465	466	499
Sulfur oxides (ppm)	160	209	175	181
Opacity (%)	26	31	30	29

Note: All values corrected to 12% CO_2

The **CO** levels for these tests were relatively low, with some variation between test runs (i.e. the maximum was 26% above the group average of 23.5 ppm).

Total hydrocarbon concentrations varied only slightly between these tests. Levels were similar to those experienced for other operating conditions. The THC(hot) analyzer showed more variation than the THC(cold) unit, however this unit was more difficult to maintain on-line and was inoperative during six of the fourteen tests.

Nitrogen oxide levels were fairly consistent between tests (i.e. within 13% of the group average).

The **hydrogen chloride** and **sulfur oxide** concentrations, showed fairly consistent results. Both the hydrogen chloride and sulfur oxide maximum and minimum concentrations were within 15% of their respective group average.

Opacity results showed little variation between tests (i.e. within 11% of the group average) however the accuracy of this data is questionable. The opacity results throughout the test program were unexpectedly high considering the relatively low particulate emission rates. Also, the sensitivity of the

instrument was poor. For example, very little change to the opacity level occurred between tests, even though significant differences in particulate concentrations were experienced.

Stack Sampling Train Results

The stack sampling train results for this test group are summarized in Table 10.5.

Table 10.5
Stack Sampling Results Under Good Operating
Conditions and Low Burning Rate

	PT-02	PT-10	PT-11	Group Average
Total Particulates (mg/Sm3)	23.7	28.9	26.3	26.3
Hydrogen Chloride (ppm)	612	463	440	505
Dioxins (ng/Sm^3)	105.1	28.5	24.2	52.6
Furans (ng/Sm^3)	178.7	81.2	83.6	114.5
Chloro-phenols (ug/Sm^3)	18.8	5.7	4.0	9.5
PAHs (ug/Sm^3)	15.5	2.8	3.0	7.1
Chlorobenzene (ug/Sm^3)	5.4	2.4	2.6	3.5
PCBs (ug/Sm^3)	10.1	0.9	1.9	4.3
Lead (ng/Sm^3)	815	1287	833	978
Mercury (ng/Sm^3)	866	704	780	783
Flue Gas Moisture (% by vol.)	13.4	11.9	13.3	12.9
Particle Size (% below 2.5um)	35	37	23	32

Note: All values corrected to 12% CO2

Particulate concentrations were relatively low, the group average being only 26 mg/Sm^3 corrected to 12% CO_2. The maximum experienced during the program was 73 mg/Sm^3 corrected to 12% CO_2. This occurred during PT-14, representing a poor operating condition. The variation experienced between tests in this test group was only about 10% as compared to the group average.

The **hydrogen chloride** (HCl) levels showed about 20% variation between tests when compared to the group average. The variation indicated by the continuous gas analyzer data was approximately 13%.

The group average indicated by the HCl sampling train results was only about 1% higher than that indicated by the continuous gas monitoring equipment.

Organic Train Stack Gas Results

The concentrations of organics in the stack gases during PT-10 and PT-11 were very similar, however PT-02 concentrations were considerably higher.

Dioxin emissions for PT-02 were approximately four times the levels experienced during the other two tests, PT-10 and PT-11. Furan stack gas concentrations for PT-02 were approximately twice the concentrations for the other two tests. These variations are shown graphically in Figure 10.5.

Similarly, PT-02 results as compared to the average of the other two tests for chlorobenzene (CB) were approximately two times higher, while polycyclic aromatic hydrocarbons (PAHs) were 5.3 times higher. Chlorophenols (CPs) were 3.9 times higher and polychlorinated biphenyls (PCBs) were 7.2 times higher.

While the concentrations of organics found in the stack gases during PT-02 were considerably different than the other two tests, no significant deviations in the process parameters or other emission levels experienced during the three tests were identified. Actually PT-02 experienced the lowest particulate and CO levels (on average) of the three tests. The testing was interrupted during PT-02 due to an abnormally high CO peak, however this interruption in testing did not cause any significant difference in operating conditions between the tests.

On the basis of the above, all three tests were considered to be representative of this operating condition and the organic concentrations for PT-02 are therefore included in the group average.

Heavy Metals Stack Gas Results

The test averages for **lead** concentrations in the stack varied somewhat, with the maximum level found being about 1.6 times greater than the minimum. The lead levels in PT-10 were highest, about 30% above the group average.

Mercury levels between group tests were fairly consistent, being within 11% of the group average.

Reference is made to Appendix A and Volume IV for other heavy metals results.

Other Test Results

Flue gas moisture between group test runs varied only slightly (less than 8% as compared to the group average).

Figure 10.5 : Dioxins and Furans - Good Operation, Low Burn

DIOXIN EMISSION

QUEBEC MASS BURN 1986

Dioxin ng/Sm3 @ 12% CO2

Performance Tests

FURAN EMISSION

QUEBEC MASS BURN 1986

Furan ng/Sm3 @ 12% CO2

Performance Tests
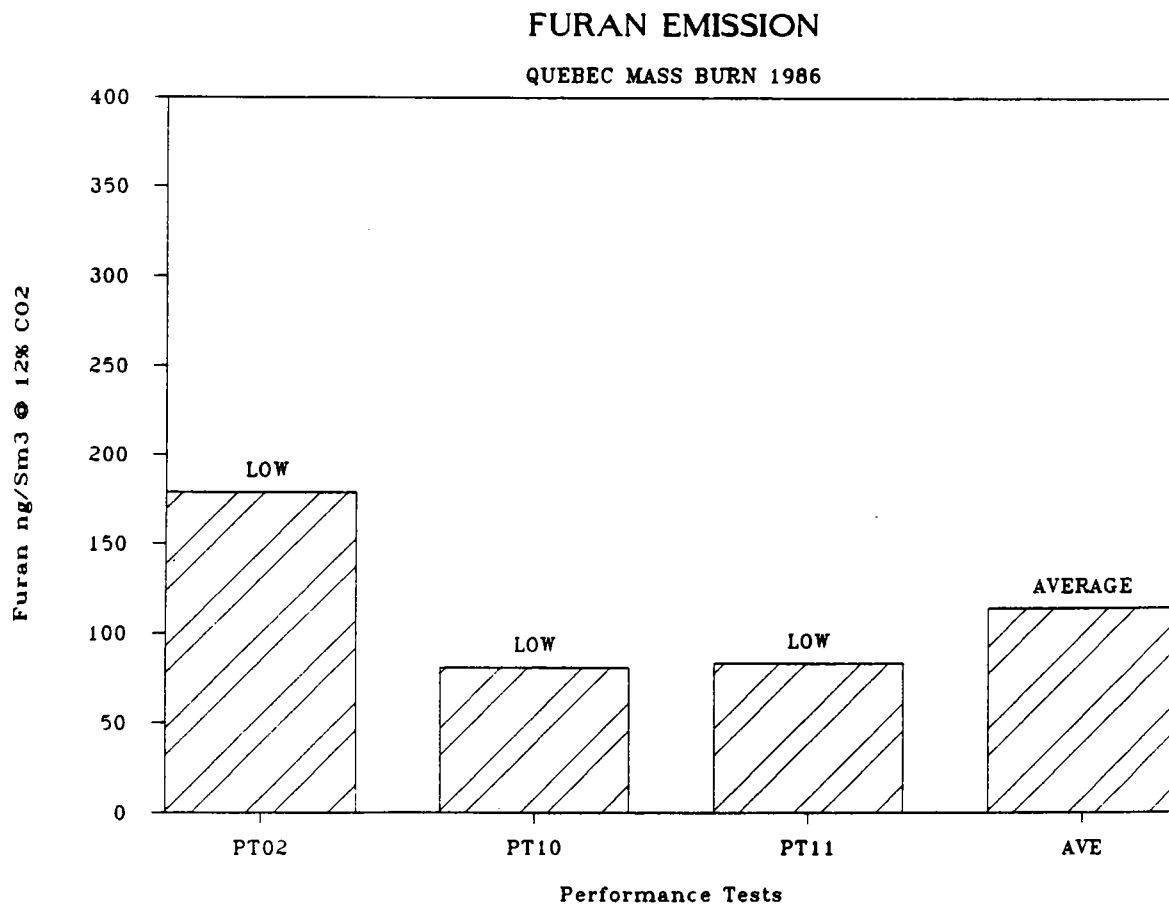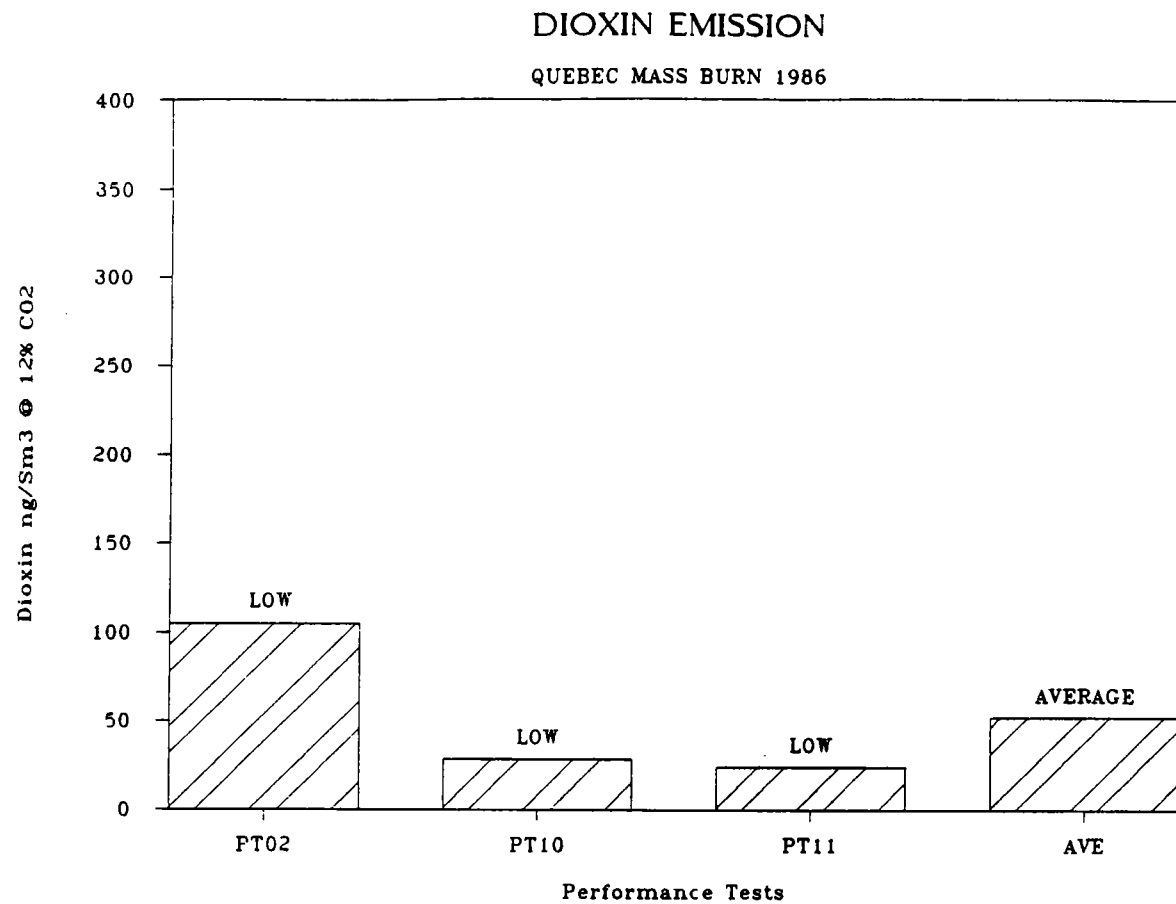
Selected **ash** and **refuse** related test results are summarized in Table 10.6. Other results are presented in Volume IV.

Table 10.6
Ash and Refuse Results Under Good Operating
Conditions and Low Burning Rate

	PT-02	PT-10	PT-11	Group Average
Boiler Ash				
Rate (% of refuse)	0.5	0.6	0.5	0.5
Carbon (% by wt)	5.9	5.9	2.3	4.7
Precipitator Ash				
Rate (% of refuse)	0.7	0.7	0.6	0.7
Carbon (% by wt)	7.2	4.8	8.6	6.9
Incinerator Bottom Ash				
Wet Rate (% refuse)	18.6	36.4	21.1	25.4
Carbon (% by wt)	4.0	3.3	0.6	2.6
Refuse				
Feed Rate (tonne/hr)	6.2	6.5	6.7	6.5
Moisture (% by wt)	38.6	32.9	39.3	36.9

Boiler and precipitator ash rates were virtually constant during this test group.

In general, the **incinerator ash** results indicated reasonably good burn-out with respect to carbon content. The rate was also reasonably good during PT-02 and PT-11, but considerably higher during PT-10, although still reasonable. No particular reason was identified which would explain the apparent higher rate. However, the difficulty in obtaining representative ash samples and in measuring the ash rate for this ash fraction must be considered when reviewing these results.

Individual test refuse feed rates were within 5% of the group average while refuse moisture during each test was within 11% of the group average.

10.2.2 Good Operating Conditions at Design Burning Rate

Three tests (PT-05, PT-06, and PT-12) were successfully completed with the incinerator operating at the design burning rate of 28 t/h and under relatively good operating conditions. Overall, the test results suggest that operation of the incinerator at these conditions represents the preferred operation mode for this type of incineration technology.

Figure 10.6 summarizes the results of this test group. Values presented are the average of the three tests. These average values are considered to be representative of incineration performance under design burning rate and good operating conditions since no significant deviations in operating conditions between replicate tests occurred. The following reviews specific process parameters and sampling program results that support this conclusion.

Process Parameter Results

Reference is made to the process parameters summary, Table 10.7.

Table 10.7
Process Parameters for Good Operating
Conditions at Design Burning Rate

	PT-05	PT-06	PT-12	Group Average
Steam Rate (tonne/hr)	28.0	28.1	27.9	28.0
Primary Air (% of total)	65	64	66	65
Secondary Air (% of total)	35	36	34	35
Radiation Chamber Temp. (°C)	1014	1030	992	1012
Boiler Inlet Temperature (°C)	813	817	785	805
Excess Air Level (%)	69	75	91	78
Input/Output Efficiency	67.3	60.5	63.3	63.7
Steaming Ratio (Kgs/Kgr) -	3.2	3.2	3.0	3.1
Flue Gas Flow Rate (Sm³/min)	828	844	953	875

The **steam** rate average was virtually the same for all three tests, approximately 28 t/h, as were the primary/secondary air ratios (65:35).

The **radiation chamber temperatures** were fairly consistent for all three tests, the maximum being only 22 C degrees above the minimum. The temperature experienced during all three test runs were consistent with the levels set by many regulatory groups (i.e. 980 to 1000°C typically) for municipal waste incineration systems.

Excess air levels were similar between tests and were significantly lower than the low burn rate, good operating condition tests. The excess air level during PT-12 was 26% higher than the average of the

OPERATING CONDITIONS

STEAM		
- FLOW	28	tonne/h
- PRESSSURE	4306	kPa
- TEMPERATURE	322	°C

TEMPERATURES		
- LOWER INCINERATOR	1012	°C
- UPPER INCINERATOR	781	°C
- BOILER INLET	805	°C
- COMBUSTION AIR	33.8	°C

AIR FLOW			RATIO
- COMBUSTION	545	Am³/min	
- PRIMARY	356	Am³/min	65 %
- SECONDARY	189	Am³/min	35 %

EFFICIENCY		
- INPUT/OUTPUT	63.7	%

REFUSE

FEED RATE	8.9	tonne/hr
MOISTURE	36	%
CALORIFIC VALUE	2862	cal/g

ORGANIC ANALYSIS		
- PCDD	32	mg/tonne
- PCDF	3.2	mg/tonne
- PCB	45	mg/tonne
- PAH	1660	mg/tonne
- CB	72	mg/tonne
- CP	1570	mg/tonne

METALS		
- Cd	6.0	g/tonne
- Pb	662	g/tonne
- Cr	200	g/tonne
- Ni	27	g/tonne
- Hg	.62	g/tonne
- Sb	2.2	g/tonne
- As	1.3	g/tonne
- Cu	245	g/tonne
- Zn	216	g/tonne
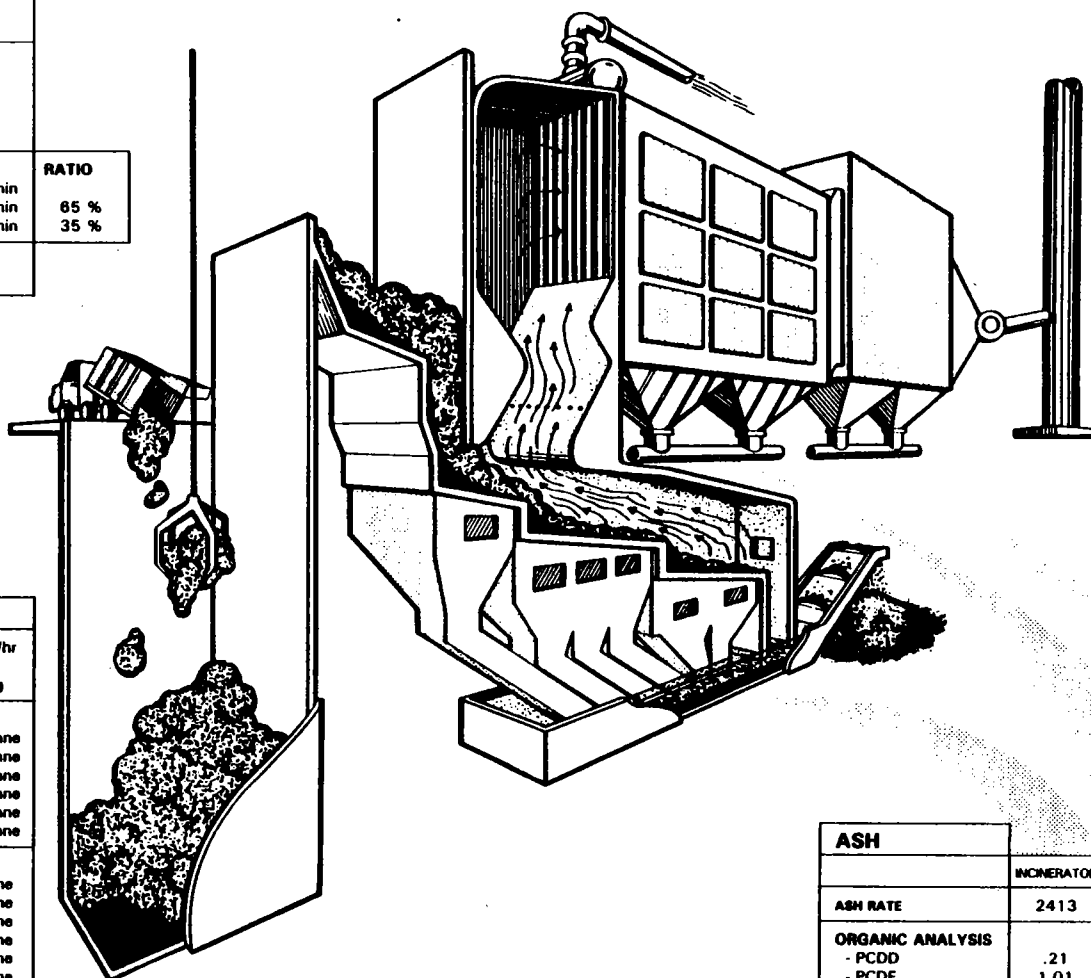
STACK EMISSIONS

GAS		
- FLOW	759	Sm³/min
- TEMPERATURE	214	°C
- MOISTURE	15.7	%
- OPACITY	33.3	%

CONTINUOUS DATA		
- O_2	9	%
- CO_2	10	%
- CO	28	ppm
- NO_x	180	ppm
- SO_2	196	ppm
- THC	2	ppm

ACID GAS		
- HCl	452	ppm

ORGANIC ANALYSIS		
- PCDD	19	ng/Sm³*
- PCDF	44	ng/Sm³*
- PCB	3025	ng/Sm³*
- PAH	4029	ng/Sm³*
- CB	3305	ng/Sm³*
- CP	5075	ng/Sm³*

PARTICULATE	22	mg/Sm³*

METALS		
- Cd	24	ug/Sm³*
- Pb	673	ug/Sm³*
- Cr	7.4	ug/Sm³*
- Ni	5.2	ug/Sm³*
- Hg	704	ug/Sm³*
- Sb	36.2	ug/Sm³*
- As	2.8	ug/Sm³*
- Cu	32.6	ug/Sm³*
- Zn	1130	ug/Sm³*

* Corrected to 12% CO_2

ASH

	INCINERATOR	BOILER	PRECIPITATOR	
ASH RATE	2413	34	57	Kg/h
ORGANIC ANALYSIS				
- PCDD	.21	37	584	ng/g
- PCDF	1.01	31	186	ng/g
- PCB	ND	ND	ND	ng/g
- PAH	638	25	111	ng/g
- CB	45	356	892	ng/g
- CP	16	80	1820	ng/g
METALS				
- Cd	3.8	206	1062	ug/g
- Pb	1757	7478	21133	ug/g
- Cr	250	304	479	ug/g
- Ni	131	115	108	ug/g
- Hg	.0311	6.8	72	ug/g
- Sb	16	332	753	ug/g
- As	6.8	91	170	ug/g
- Cu	2543	530	1483	ug/g
- Zn	1783	17400	60700	ug/g

FIGURE 10.6
GOOD OPERATING CONDITIONS, DESIGN BURNING RATE
PERFORMANCE TEST SUMMARY — PT05/06/12

other two tests in this group, 17% above the group average. This variation was not considered to be significant.

Input/output efficiencies were highest for PT-05. This result is consistent with the low excess air and apparent low carbon content in the incinerator ash. The steaming ratio showed little variation; all three tests were within 6% of the group average.

The **flue gas** flow rate was fairly consistent between tests, being within 9% of the group average. The highest rate (PT-12) was 15% above the lowest rate (PT-05).

Continuous Gas Results

The continuous flue gas monitoring data for this group of tests are summarized in Table 10.8.

Table 10.8
Continuous Flue Gas Data Under Good Operating
Conditions and Design Burning Rate

	PT-05	PT-06	PT-12	Group Average
Carbon monoxide (ppm)	20.4	26.6	36.7	27.9
Total hydrocarbons				
cold (ppm)	1.4	1.8	2.1	1.8
hot (ppm)	N/A	N/A	4.3	-
Nitrogen oxides (ppm)	172	169	199	180
Hydrogen chloride (ppm)	504	366	487	452
Sulfur oxides (ppm)	178	186	225	196
Opacity (%)	32	29	39	33

Note: All values corrected to 12% CO_2

The CO levels for these tests were relatively low with some variation between test runs. The maximum was 32% above the group average of 28 ppm. This difference is not significant considering the low levels of CO experienced during these tests. (i.e. only 16 ppm between tests).

THC(hot) results were not obtained for PT-05 or PT-06 as the analyzer was off-line during these tests. Maintaining the THC(hot) analyzer on line was difficult compared with the THC(cold) analyzer. THC(cold) concentrations were relatively low for all tests.

Nitrogen oxide concentrations were relatively consistent between tests, all being within 11% of the group average.

The **hydrogen chloride** concentration was fairly consistent between tests. The maximum was 38% above the minimum, 12% above the group average.

The **sulfur oxide** concentrations for each test were also fairly consistent. The maximum was 26% above the minimum, 15% above the group average.

Opacity for PT-12 was 28% above the average of the other two tests, 18% above the group average. As previously indicated, the accuracy of this equipment was questionable. While PT-05 showed a higher level of opacity than during PT-06, the particulate concentration was actually higher during PT-06.

Stack Sampling Train Results

The stack sampling train results for this test group are summarized in Table 10.9.

Table 10.9
Stack Sampling Results Under Good Operating
Conditions and Design Burning Rate

	PT-05	PT-06	PT-12	Group Average
Total Particulates (mg/Sm3)	15.8	20.5	30.7	22.3
Hydrogen Chloride (ppm)	504	366	487	452
Dioxins (ng/Sm3)	12.8	11.0	32.6	18.8
Furans (ng/Sm3)	49.4	31.6	52.5	44.5
Chloro-phenols (ug/Sm3)	5.8	4.3	5.1	5.1
PAHs (ug/Sm3)	3.9	5.8	2.3	4.0
Chlorobenzene (ug/Sm3)	3.5	3.0	3.4	3.3
PCBs (ug/Sm^3)	2.5	4.5	2.0	3.0
Lead (ng/Sm^3)	421	496	1100	673
Mercury (ng/Sm^3)	807	717	589	704
Flue Gas Moisture (% by vol.)	15.8	16.4	14.7	15.6
Particle Size (% below 2.5 um)	40	24	23	29

Note: All values corrected to 12% CO_2

Particulate concentrations varied somewhat between tests. The results for PT-12 were twice the values for PT-05. However, all concentrations were relatively low. The higher level experienced in PT-12 was consistent with the opacity data presented previously. At these low levels, the particulate concentration variation was not significant. The maximum test concentration was only 15 mg/Sm^3 above the minimum.

The **hydrogen chloride** concentrations were fairly consistent. The maximum test concentration (PT-12) was 24% above the group average. When compared to the group average indicated by the continuous gas monitor data, the stack sampling train showed 20% lower HCl levels, the reverse of the difference found between sampling train and continuous HCl monitor results for the low burning rate.

Organic Train Stack Gas Results

Dioxin Stack gas concentrations for each of the three tests varied from the minimum being 41% less than the group average (19 ng/Sm^3) to the maximum being 73% greater than the group average. This variation was not particularly significant considering the relatively low levels that were achieved for all tests in this group. This group average was the lowest of all test groups, 5 times lower than the highest group average. The dioxin level for PT-12 was almost 3 times higher than the average of the other two tests. In reviewing the possible cause of the higher dioxin levels for PT-12, no significant factor could be identified. While the previous discussion noted that PT-12 was conducted under slightly higher excess air levels and experienced higher particulate and CO concentrations than the other two tests, these variations were not significant. Other key parameters such as radiation chamber temperature and primary/secondary air ratio were virtually the same for PT-12 as compared to the other two tests. Also, all other organics including furans showed no significant differences between tests. It was therefore concluded that all three tests were representative of the operating condition and that the group average for dioxin and the other organics should be based on all three tests.

The **furan** stack gas levels experienced revealed the maximum for PT-12 being only 6% higher than that of PT-05 yet 66% higher than that of PT-06.

The variation in dioxin and furan stack gas concentrations between the three tests is shown graphically in Figure 10.7.

The stack gas concentrations of **CPs** and **CBs** were fairly consistent (within 16% of the group average).

PCB and **PAH** stack gas concentrations showed a greater variation, the maximum exceeding the minimum in both cases by a factor of two.

The maximums for organics other than dioxins and furans occurred either with PT-05 or PT-06, not PT-12.

Figure 10.7 : Dioxins and Furans - Good Operation, Design Burn
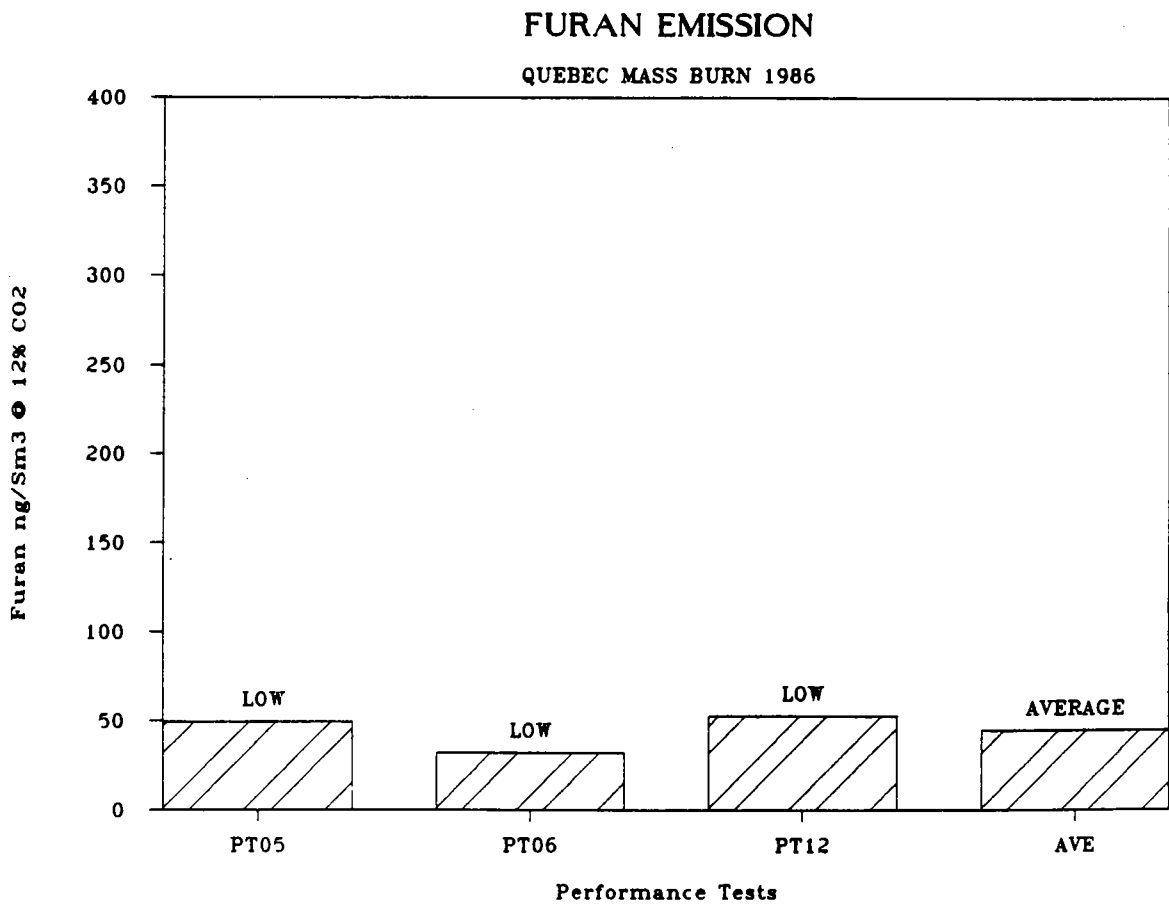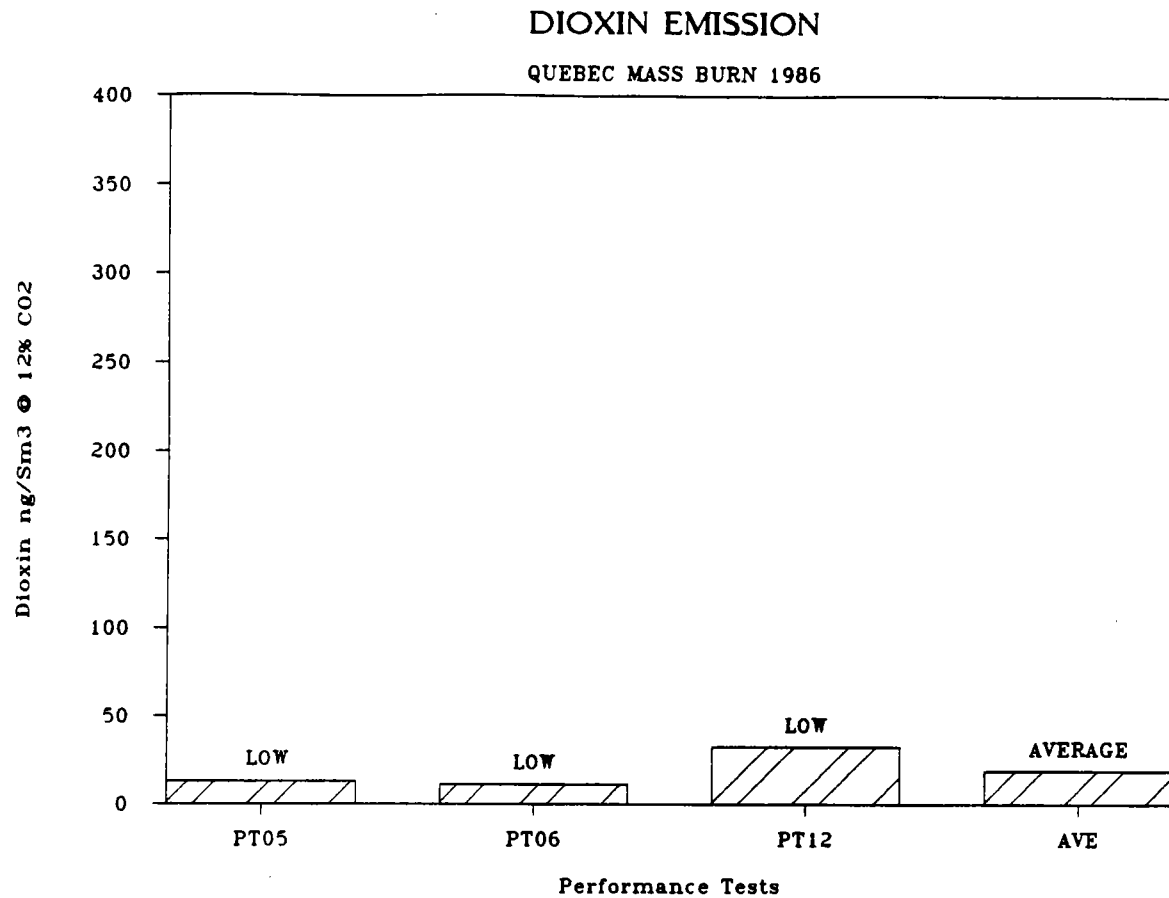
DIOXIN EMISSION

QUEBEC MASS BURN 1986

Dioxin ng/Sm3 @ 12% CO_2

| | LOW | LOW | LOW | AVERAGE |
| PT05 | PT06 | PT12 | AVE |

Performance Tests

FURAN EMISSION

QUEBEC MASS BURN 1986

Furan ng/Sm3 @ 12% CO_2

| | LOW | LOW | LOW | AVERAGE |
| PT05 | PT06 | PT12 | AVE |

Performance Tests

Heavy Metals Stack Gas Results

The test averages for **lead** concentrations in the stack varied considerably, the maximum being about 2.6 times higher than the minimum.

Mercury levels were relatively consistent with all tests being within 17% of the group average.

While lead levels were highest for PT-12, mercury levels were lowest.

Reference is made to Appendix A and Volume IV for other heavy metal results.

Other Test Results

Flue gas moisture between these tests varied only slightly (less than 6% as compared to the group average).

Selected ash and refuse related test data are summarized in Table 10.10. Other results are presented in Appendix A and Volume IV.

Table 10.10
Ash and Refuse Results Under Good Operating
Conditions and Design Burning Rate

	PT-05	PT-06	PT-12	Group Average
Boiler Ash				
Rate (% of refuse)	0.4	0.3	0.5	0.4
Carbon (% by wt)	15.5	7.2	1.3	8.0
Precipitator Ash				
Rate (% of refuse)	0.5	0.6	0.8	0.6
Carbon (% by wt)	8.0	36.9	7.1	17.3
Incinerator Bottom Ash				
Wet Rate (% refuse)	26.6	31.2	23.7	27.2
Carbon (% by wt)	1.5	11.9	4.1	5.8
Refuse				
Feed Rate (tonne/hr)	8.7	8.7	9.3	8.9
Moisture (% by wt)	36.8	38.3	30.9	35.3

Boiler and precipitator fly ash rates varied little between tests. The carbon content in the boiler ash varied considerably between tests, with PT-12 having the low level of 1.3%, PT-05 the high at 15.5%.

The precipitator ash carbon content also varied significantly, again PT-12 being lowest at 7.1% with PT-06 showing a very high carbon content of 36.9%. Since most process parameters and emissions showed no similarly significant variations, a certain level of skepticism should be exercised when reviewing these results.

The incinerator ash rate indicated reasonably good burnout on a rate basis, and with the exception of PT-06, reasonably low carbon content. As with the previous low rate good burn results, carbon content in the incinerator ash appears to have varied significantly between test results (i.e. PT-06's carbon content was 8 times higher than PT-05's). It was difficult to obtain representative samples of the bottom ash. For this test group some unburnables were evident in the bottom ash during this test as noted in the detailed review of PT-06 in Appendix C. This would indicate that a higher carbon content could be expected in this instance.

Individual test refuse feed rates were within 5% of the group average while refuse moisture varied up to approximately 12% as compared to the group average.

10.2.3 Good Operating Conditions at High Burning Rate

Three tests (PT-07, PT-09 and PT-13) were performed with the incinerator operating at the high burning rate of 32 t/h (15% above the design burning rate) and under relatively good operating conditions.

Figure 10.8 summarizes the results of this test group. Values presented are the average of the results of the first two tests (PT-07 and PT-09), and were considered to be representative of incinerator performance under high burning rate and good operating conditions. The third test (PT-13) was not included in the group average since the conditions experienced during this test run were not comparable to the other two test runs. As indicated in Appendix C, during this test operators experienced considerable difficulty in maintaining steady operation. This was apparently due to apparently wet slugs of refuse and slag build-up restrictions, both resulting in unusually frequent CO peaks.

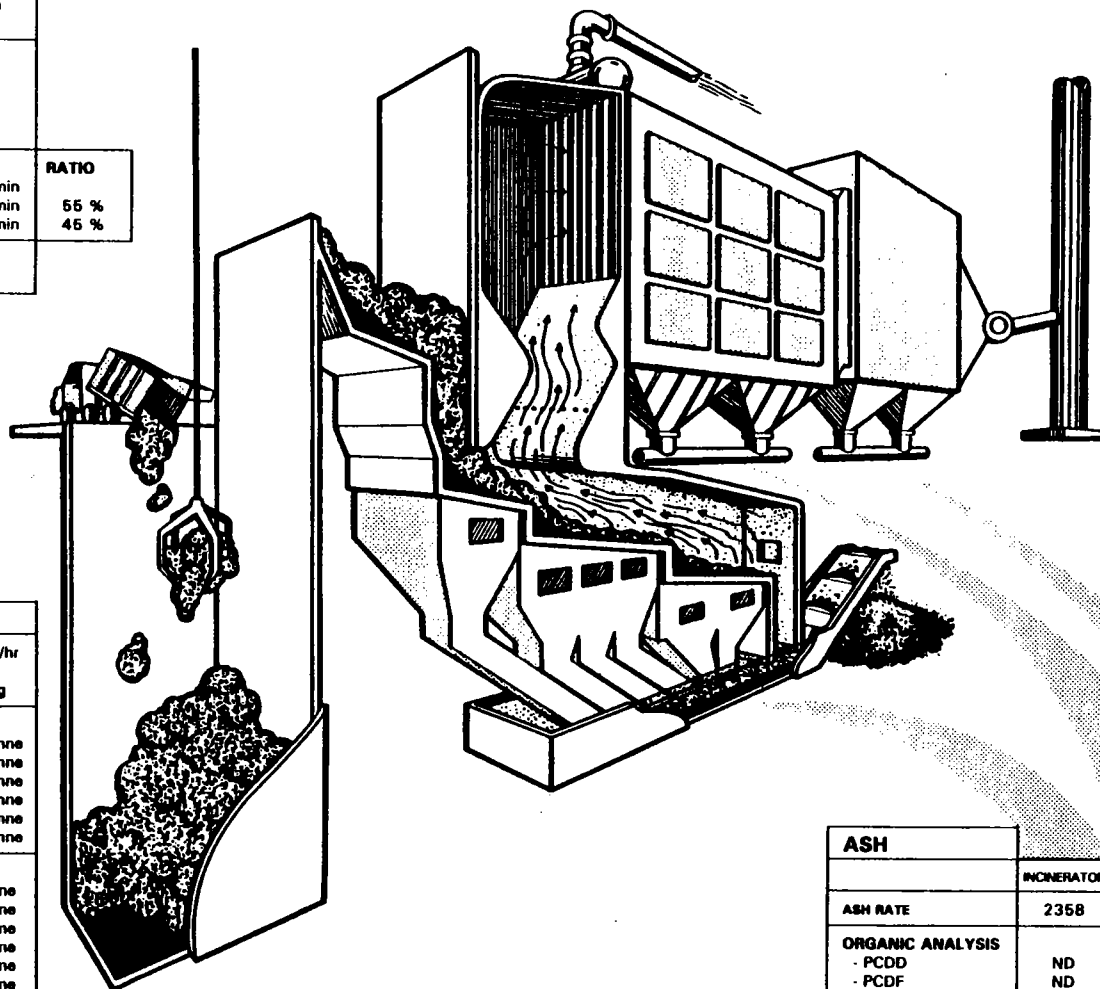The following reviews specific process parameters and sampling program results for each of the tests. Those factors are also reviewed which support the conclusion that the group average should be based on PT-07 and PT-09 (excluding PT-13 results).

Process Parameters Results

Reference is made to the process parameters summary Table 10.11.

The **steam** rate average of 32 tonne/hr for the three tests was the same.

OPERATING CONDITIONS

STEAM		
- FLOW	31.8	tonne/h
- PRESSURE	4408	kPa
- TEMPERATURE	324	°C

TEMPERATURES		
- LOWER INCINERATOR	1045	°C
- UPPER INCINERATOR	815	°C
- BOILER INLET	823	°C
- COMBUSTION AIR	28.2	°C

AIR FLOW			RATIO
- COMBUSTION	688	Am³/min	
- PRIMARY	378	Am³/min	55 %
- SECONDARY	310	Am³/min	46 %

EFFICIENCY		
- INPUT/OUTPUT	66.2	%

STACK EMISSIONS

GAS		
- FLOW	965	Sm³/min
- TEMPERATURE	226	°C
- MOISTURE	14.9	%
- OPACITY	33	%

CONTINUOUS DATA		
- O_2	10	%
- CO_2	10	%
- CO	43	ppm
- NO_x	194	ppm
- SO_2	160	ppm
- THC	2	ppm

ACID GAS		
- HCl	441	ppm

ORGANIC ANALYSIS		
- PCDD	55	ng/Sm³*
- PCDF	101	ng/Sm³*
- PCB	4845	ng/Sm³*
- PAH	5382	ng/Sm³*
- CB	4321	ng/Sm³*
- CP	7988	ng/Sm³*

PARTICULATE	36	mg/Sm³*

METALS		
- Cd	40.6	ug/Sm³*
- Pb	1599	ug/Sm³*
- Cr	14.8	ug/Sm³*
- Ni	8	ug/Sm³*
- Hg	872	ug/Sm³*
- Sb	43.6	ug/Sm³*
- As	4.5	ug/Sm³*
- Cu	53.9	ug/Sm³*
- Zn	2061	ug/Sm³*

* Corrected to 12% CO_2

REFUSE

FEED RATE	9.7	tonne/hr
MOISTURE	35	%
CALORIFIC VALUE	2892	cal/g

ORGANIC ANALYSIS		
- PCDD	16	mg/tonne
- PCDF	.054	mg/tonne
- PCB	69	mg/tonne
- PAH	10400	mg/tonne
- CB	23	mg/tonne
- CP	2060	mg/tonne

METALS		
- Cd	6.7	g/tonne
- Pb	197	g/tonne
- Cr	60	g/tonne
- Ni	19	g/tonne
- Hg	.36	g/tonne
- Sb	5.4	g/tonne
- As	.6	g/tonne
- Cu	48	g/tonne
- Zn	327	g/tonne

ASH

	INCINERATOR	BOILER	PRECIPITATOR	
ASH RATE	2358	54	95	Kg/h
ORGANIC ANALYSIS				
- PCDD	ND	23	620	ng/g
- PCDF	ND	26	257	ng/g
- PCB	ND	ND	ND	ng/g
- PAH	498	21	103	ng/g
- CB	4	531	1663	ng/g
- CP	20	102	1701	ng/g
METALS				
- Cd	2.8	153	764	ug/g
- Pb	867	6635	17150	ug/g
- Cr	363	338	516	ug/g
- Ni	428	101	118	ug/g
- Hg	.0418	5.9	73	ug/g
- Sb	9	270	525	ug/g
- As	8.3	74	130	ug/g
- Cu	4509	480	1295	ug/g
- Zn	1531	15660	44750	ug/g

FIGURE 10.8
GOOD OPERATING CONDITIONS, HIGH BURNING RATE
PERFORMANCE TEST SUMMARY — PT07/09

Table 10.11
Process Parameters for Good Operating
Conditions and High Burning Rate

	PT-07	PT-09	Group Average	PT-13
Steam Rate (tonne/hr)	31.8	31.8	31.8	31.6
Primary Air (% of total)	49	60	55	63
Secondary Air (% of total)	51	40	46	37
Radiation Chamber Temp. (°C)	1085	1006	1046	997
Boiler Inlet Temp. (°C)	836	809	823	799
Excess Air Levels (%)	84	84	84	92
Input/Output Efficiency (%)	67.9	64.4	66.2	58.8
Steaming Ratio (Kgs/Kgr) -	3.7	2.9	3.3	2.8
Flue Gas Flow Rate (Sm³/min)	945	985	965	1036

Note: PT-13 results are not included in the group average

The **primary/secondary air** ratios varied considerably between tests as compared to the design rate tests. The incinerator operating at this higher burning rate tended to be unstable as compared to the design rate. At certain times during PT-13, the primary air rate approached the levels experienced during PT-14 and PT-15. Such high primary air rates represented one of the most significant characteristics of PT-14 and PT-15. It was therefore a concern that the high rates experienced during PT-13 may have occurred over a long enough period to result in too great a deviation from PT-07 and PT-09 conditions.

The **radiation chamber temperatures** were relatively high as intended, but were not as consistent for this burning rate as for the good operating conditions at the low and design burning rates. The maximum was 79 C degrees above the minimum test average. The average temperature for PT-09 was similar to PT-13 (within 9 C degrees); no significant short-term variations were noted.

Reference is made to Volume IV for the graphical presentation of the variations of primary air and radiation chamber temperature during each test.

The average **excess air** levels were the same for PT-07 and PT-09; PT-13 was within 10% of the group average. Thus, excess air variations during this test group were not significant.

The **input/output efficiency** and **steaming ratio** were both higher for PT-07 as compared to PT-13. This result was consistent with the higher flue gas moisture content and higher incinerator bottom ash and carbon content experienced during PT-13 as compared to PT-07.

The **flue gas flow** rates were, on average, consistent between tests, the maximum being within 5% of the minimum. PT-13 experienced the highest rate.

Continuous Gas Results

The continuous flue gas monitoring data for the test group are summarized in Table 10.12.

Table 10.12
Continuous Gas Data Under Good Operating
Conditions and High Burning Rate.

	PT-07	PT-09	Group Average	PT-13
Carbon monoxide (ppm)	42.7	43.3	43	77.3
Total Hydrocarbons,				
cold (ppm)	1.8	1.5	1.7	1.5
hot (ppm)	N/A	N/A	N/A	N/A
Nitrogen oxides (ppm)	186	202	194	205
Hydrogen chloride	512	369	441	500
Sulfur oxides (ppm)	192	128	160	178
Opacity (%)	35.4	29.6	32.5	36.3

Note: All values corrected to 12% CO2
PT-13 results are not included in the group average

The CO levels for these tests were relatively high as compared to the low on the design burning rate, good operating condition tests. While PT-07 and PT-09 experienced virtually the same concentration, PT-13 was 80% higher than the average of the other two tests. PT-13 also experienced several higher CO peaks than the other two tests, indicating unstable operation during this test. While the PT-13 CO concentration was not as high as those experienced during PT-14 and PT-15, it was equivalent to those experienced during PT-02 and PT-04. This relatively high CO result reinforced the conclusion that PT-13 had deviated excessively from the intended operating condition. Based on CO results, PT-13 therefore was not a replicate of PT-07 and PT-09. In many ways it was more similar to conditions experienced during the poor operating condition runs that are reviewed in Section 10.4.

Total hydrocarbon (hot) results were not obtained for this test group due to instrument failure. Total hydrocarbon (cold) test results were all relatively low, with no significant variation between tests evident.

Nitrogen oxide levels were fairly consistent between tests, the maximum approximately 10% greater than the minimum.

The **hydrogen chloride** concentration variations were similar to other test group results, the maximum being 39% above the minimum.

The **sulfur oxide** concentrations varied somewhat, the maximum concentration being 1.5 times the minimum.

The **opacity** results showed little variation between tests, PT-13 being slightly higher than PT-07. The test result for PT-09 was about 16% lower than for PT-07 even though particulate concentrations were virtually the same. As previously indicated, the accuracy of the equipment was questionable.

Stack Sampling Train Results

The stack sampling train results for this test group are summarized in Table 10.13.

Particulate concentrations were relatively high compared to the low and design burning rate tests under good operating conditions. However, this is consistent with a higher feed rate. The total particulate concentration for PT-13 was considerably higher than the average of the other two tests for this operating mode (i.e. 51% higher). This higher level experienced during PT-13 was typical of the concentrations experienced during the poor operating conditions demonstrated during PT-03, PT-04, PT-14 and PT-15. The concentrations experienced during PT-07 and PT-09 were almost identical to each other. This relatively high and differing particulate concentration reinforced the conclusion that PT-13 was not representative of this test group.

The **hydrogen chloride** concentrations measured by the sampling train varied by 85 ppm between maximum and minimum tests while the continuous gas results, varied by 143 ppm. On a group average basis, the sampling train results were 14% lower than the group average indicated for the continuous monitoring equipment. There was a 10% difference between results of the two test methods in the case of PT-13.

Organic Train Stack Gas Results

The **dioxin** concentrations for this test group were considerably higher than the concentrations measured at the design burning rate under good operating conditions. PT-13 had particularly high dioxin levels, 3 times the average of the other two tests for this operating mode. The higher level experienced during PT-13 was not surprising. The previously identified aspects of this test made it

Table 10.13
Stack Sampling Results Under Good Operating
Conditions and High Burning Rate

	PT-07	PT-09	Group Average	PT-13
Total Particulates (mg/Sm3)	35.3	35.9	35.6	53.7
Hydrogen Chloride (ppm)	512	369	441	500
Dioxins (ng/Sm3)	45.4	65.3	55.4	163.6
Furans (ng/Sm3)	100.9	100.4	100.7	118.4
Chloro-phenols (ug/Sm3)	6.6	9.4	8.0	10.0
PAHs (ug/Sm3)	2.7	8.1	5.4	3.2
Chlorobenzene (ug/Sm3)	3.6	5.1	4.4	6.4
PCBs (ug/Sm^3)	2.4	7.3	4.9	1.6
Lead (ng/Sm^3)	1239	1959	1599	1839
Mercury (ng/Sm^3)	1099	644	872	824
Flue Gas Moisture (% by vol.)	13.8	16.1	15.0	15.2
Particle Size (% below 2.5 um)	36	11	24	21

Note: All Values corrected to 12% CO_2
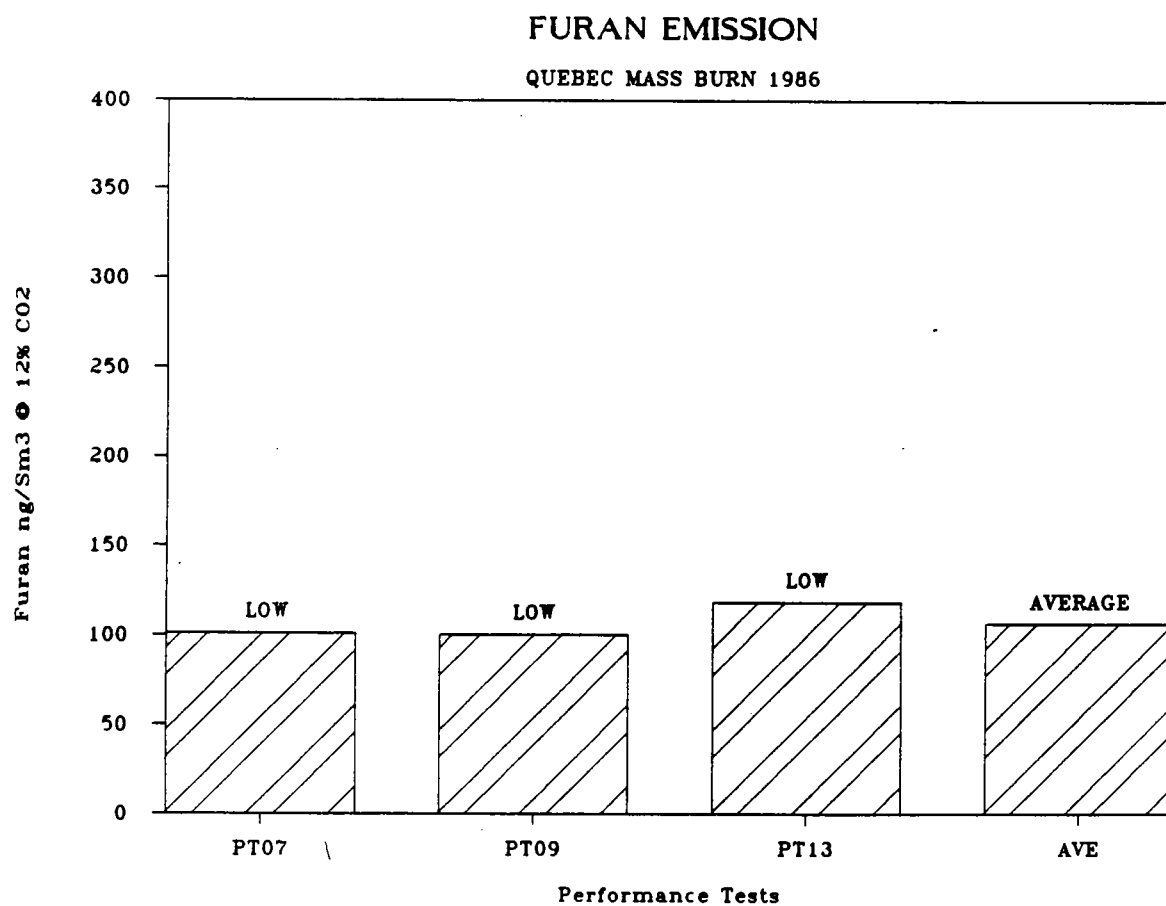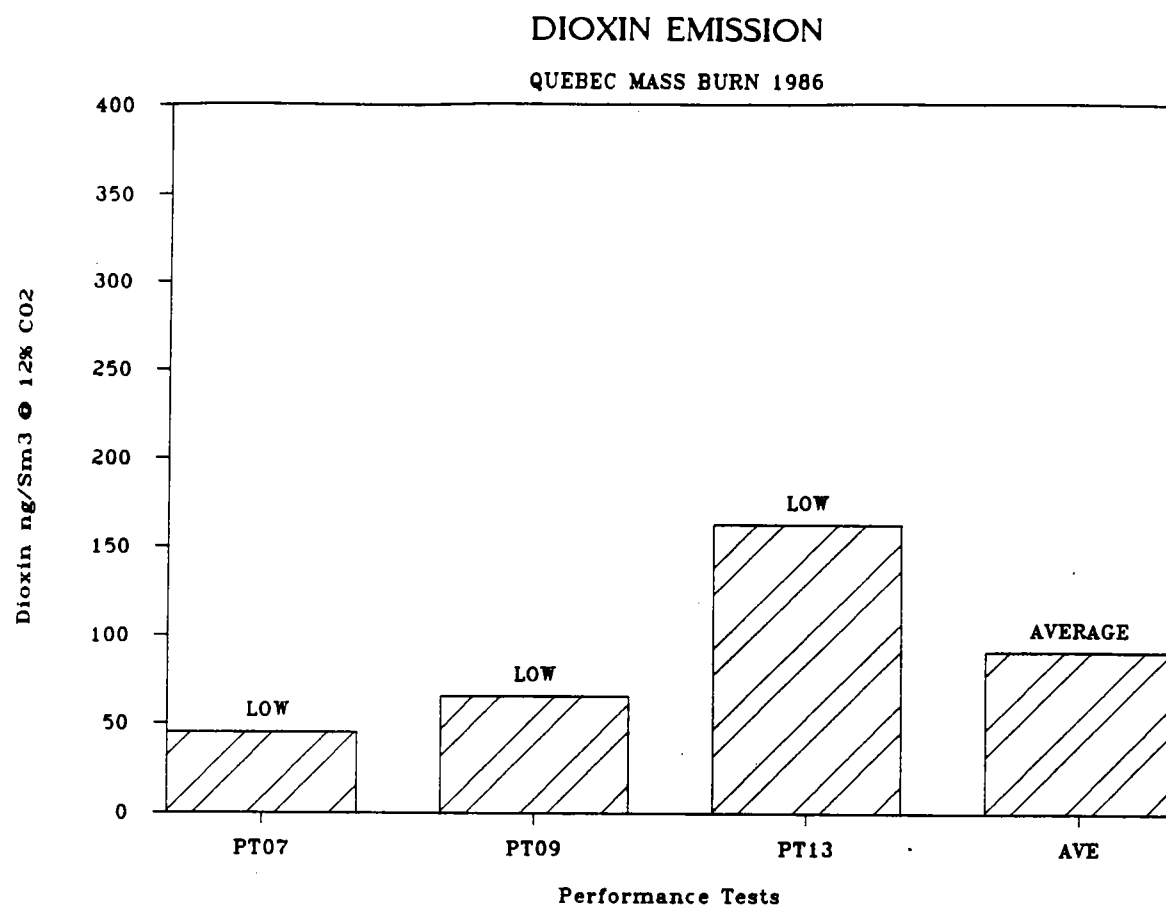PT-13 results are not included in the group average

different from the other two tests and resulted in several characteristics (CO, particulate, primary air,

instability) being more typical of poor operating conditions. This higher dioxin concentration was not considered representative of the levels that might be expected during high burning rate, good operating conditions and was therefore excluded from the group average.

Furan concentrations were consistent during the three tests. Concentrations during PT-07 and PT-09 were identical while PT-13 experienced about 18% higher concentrations.

The variation in dioxin and furan stack gas concentrations between the tests is shown graphically in Figure 10.9.

Concentrations of other organics in the stack gases did not vary significantly from the design burning rate, good operating conditions, although generally the variation of concentrations between tests was greater at the high burning rate conditions. PT-13 experienced only slightly higher CP and CB levels

Figure 10.9 : Dioxins and Furans - Good Operation, High Burn

DIOXIN EMISSION

QUEBEC MASS BURN 1986

Dioxin ng/Sm3 @ 12% CO2 vs Performance Tests. Bars: PT07 LOW ~45, PT09 LOW ~65, PT13 LOW ~160, AVE AVERAGE ~90.

FURAN EMISSION

QUEBEC MASS BURN 1986

Furan ng/Sm3 @ 12% CO2 vs Performance Tests. Bars: PT07 LOW ~100, PT09 LOW ~100, PT13 LOW ~115, AVE AVERAGE ~105.

as compared to the other two tests, with the highest PCB and PAH concentrations occurring during PT-09.

Heavy Metals Stack Gas Results

The **lead** concentrations in the stack were relatively high. All three tests were well above the levels experienced during the design burning rate good operating condition tests. The maximum occurred during PT-09, although PT-13 was within 7%.

The **mercury** concentrations in the stack gases differed from the lead results in that the lowest concentration for mercury was experienced during PT-09. This result was similar to the design burning rate, good operating condition tests where the highest lead level test had the lowest mercury concentration.

Reference is made to Appendix A and Volume IV for other heavy metal results.

Other Test Results

Flue gas moisture between these tests was consistent, all tests being within 8% of the group average.

Selected **ash and refuse** test data are summarized in Table 10.14. Other results are presented in Appendix A and Volume IV.

Table 10.14
Ash and Refuse Results Under Good Operating
Conditions and High Burning Rate

	PT-07	PT-09	Group Average	PT-13
Boiler Ash				
Rate (% of refuse)	0.5	0.5	0.5	0.5
Carbon (% by wt)	21.9	23.7	22.8	1.3
Precipitator Ash				
Rate (% of refuse)	0.8	0.9	0.9	1.1
Carbon (% by wt)	11.8	9.4	10.6	7.4
Incinerator Bottom Ash				
Wet Rate (% refuse)	22.0	21.5	21.8	25.3
Carbon (% by wt)	7.5	2.8	5.2	14.6
Refuse				
Feed Rate (tonne/hr)	8.6	10.8	9.7	11.3
Moisture (% by wt)	32.3	37.2	34.8	37.2

Boiler and precipitator ash rates were fairly consistent between tests, the former being identical for all three tests.

The carbon content in the **boiler fly ash**, while similar and quite high for PT-07 and PT-09, was very low for PT-13. The high carbon content also occurred during the design rate, good operating test group. This unexpected variation could not be explained and these results should be reviewed with a certain level of skepticism.

The precipitator ash carbon content during each test was more consistent; PT-13 apparently experienced the lowest carbon content.

The **incinerator ash** rate was virtually the same for PT-07 and PT-09, about 7% higher for PT-13. These bottom ash rates were quite low for municipal waste incineration processing. Typically 20% to 40% of the raw waste feed can be anticipated for this technology.

The **carbon content** in the incinerator ash was relatively high during PT-13; PT-09 showed the lowest level. While this data should be reviewed skeptically, as noted previously, the detailed discussion in Appendix C does indicate that poor bottom ash quality was observed during PT-13.

Individual test **refuse feed rates** varied more during this operating condition than during the low and design burning rate, good operating conditions. For example the maximum feed rate was 31% greater than the minimum for this test group while for the low and design burning rate, good operating condition groups, the maximums were only 8% and 7% greater than the minimums respectively.

The **moisture** levels in the refuse for each individual test varied between 32% and 37%, slightly less than the variation experienced during the other good operating condition test groups.

10.3 DESIGN BURNING RATE - POOR OPERATING CONDITIONS

This section presents and discusses the test results that were experienced within the two poor operating condition test groups.

This section also compares the group averages developed for the two poor test group operating conditions with the good operating condition group averages developed in sub-section 10.2.2.

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10.3.1 Poor Operating Condition Tests Set-up - General

Four tests, PT-03, PT-04, PT-14 and PT-15 were undertaken to establish the performance of the incineration system under poor operating conditions. These four tests actually involved two distinctly different poor operating modes. All tests were run at the design burning rate of 28 t/h steam.

For this test group, the two operating conditions were duplicated rather than triplicated. Restricting the program to duplicate tests at the poor operating conditions and at the design burning rate only was necessary to maintain program costs within the allotted project budget. For example, if triplicate testing of both poor operating conditions was attempted under design, high and low burning rates, the program would have had 14 more tests, doubling the program costs.

The Low Temperature Operating Conditions Test Group Classification

The four tests reviewed in this section were designated as representing "poor" operating conditions based on the results of the Characterization Test program. These poor tests involved operating conditions which, for this technology do not represent modern operating practice. For example, the first pair of tests, PT-03 and PT-04 were operated with an high excess air levels and a radiation chamber temperature of approximately 850°C. This temperature is below the level that is now being required by many regulatory groups. Operation of modern facilities is typically at the higher temperatures to ensure complete combustion of the organics in the flue gases. The high excess air level was required to cool the flue gases to achieve the lower temperature conditions.

This test group was undertaken to demonstrate conditions when other parameters remained unchanged, i.e., the effect of temperature on the performance of this technology, particularly with respect to dioxin and furan concentrations in the flue gas.

The Poor Combustion Air Distribution Test Group Classification

The second group of tests undertaken with poor operating conditions involved operation of the system at relatively high temperature conditions in the radiation chamber and only minimal overfire air supplied to the system. As determined during the Characterization Tests, this mode of operation results in incomplete combustion of the exhaust gases as indicated by high CO concentrations. Due to the limited overfire air rate, it also results in high underfire air rates for the same excess air level and steam rate condition. The high underfire air rates significantly increase the rate at which particulates lift off the burning refuse bed and enter the precipitator. It also results in flame impingement on the boiler tubes which can cause damage to the boiler equipment.

The one benefit this operating mode does offer is an apparent improvement in the ash quality due to the higher underfire air rates (i.e. less visibly detectable unburnables). Because of this latter feature and the relatively high operating temperature that can be achieved, this so-called poor mode of operation is often practiced by operators, and in fact represented the normal operating mode for this

facility prior to completion of the design modifications (April 1986). Without continuous monitoring of CO in the flue gas, operators have no way of knowing whether combustion is being completed. The results of this test group indicate that high temperatures in the radiation chamber do not in themselves ensure low CO levels and efficient combustion if insufficient secondary air is supplied. Modern state-of-the-art facilities using this technology have now recognized the need to maintain good primary/secondary air ratios and high burning temperatures in order to complete combustion satisfactorily.

This poor test group was undertaken to demonstrate the effect of minimal secondary air supply on the performance of this technology, particularly with respect to dioxin and furan concentrations in the flue gas when other parameters remained unchanged.

10.3.2 Summary of Poor Operating Condition Results

Figures 10.10 and 10.11 summarize the results of the two poor operating condition test groups. Values presented are the average of the results of the two tests within the group. These average values are considered to be representative of incinerator performance at design burning rate and poor operating conditions.

The following reviews specific process parameters and sampling program results that support this conclusion. Comparisons are also made between the poor and good operating condition group averages.

Process Parameter Results

Reference is made to the process parameters summary, Table 10.15.

The average **steam rates** for both poor operating condition test groups were consistent.
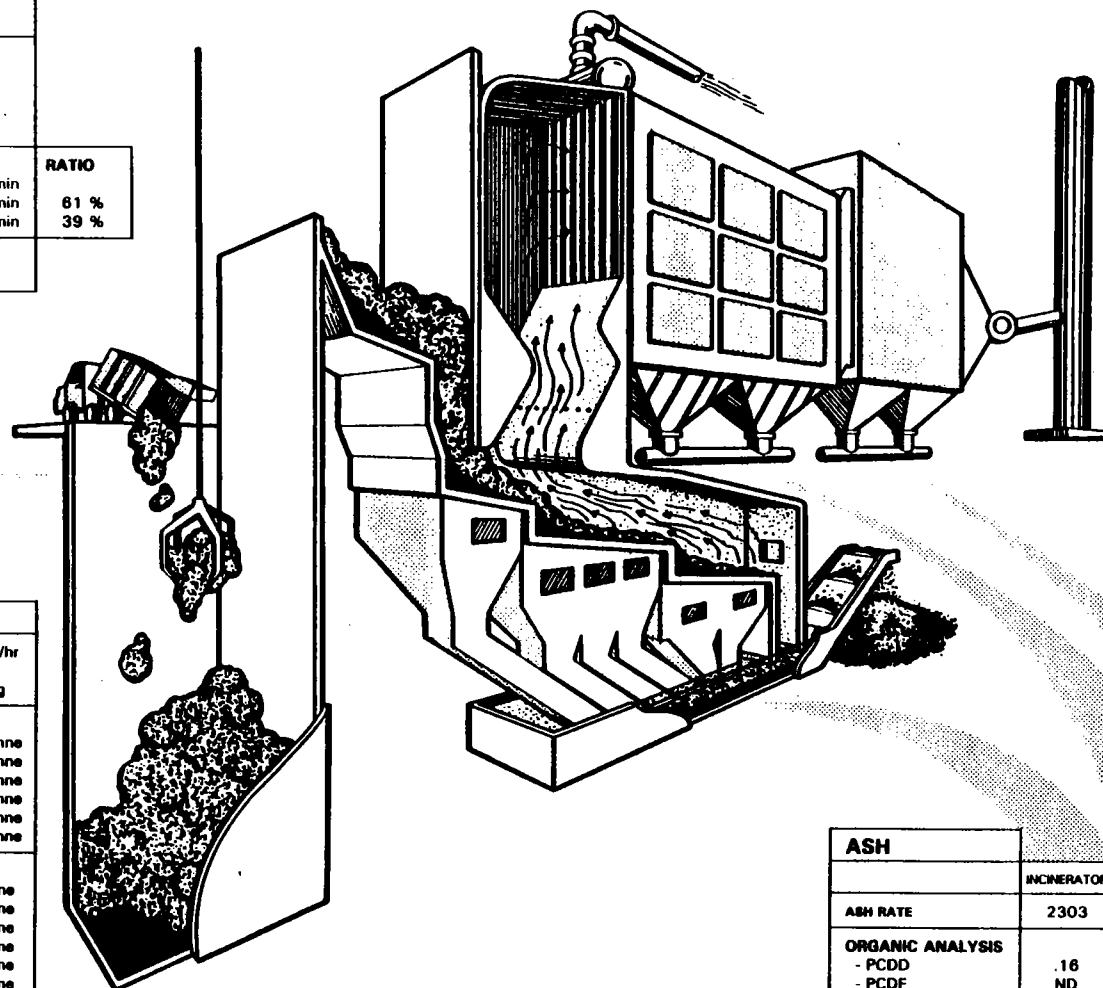
The **primary/secondary air** distribution parameter was duplicated for the two poor operating condition test groups. The low temperature group experienced distributions that were similar to the good operating condition test group average. The poor distribution tests were also similar to each other with a very low secondary air percentage as intended.

The **radiation chamber temperature** for the low temperature tests were duplicated with the group average being 153 C degrees below the good operating condition, design rate test group average.

The **radiation chamber temperature** for the poor distribution tests varied more than during the low temperature tests. This operating condition resulted in higher temperatures (i.e. greater than 100 C degrees, on average) than PT-03 and PT-04. This temperature was relatively high but lower than for the good operating conditions, the design steam rate, by 34 C degrees.

OPERATING CONDITIONS

STEAM		
- FLOW	28	tonne/h
- PRESSSURE	4312	kPa
- TEMPERATURE	323	°C
TEMPERATURES		
- LOWER INCINERATOR	858	°C
- UPPER INCINERATOR	664	°C
- BOILER INLET	712	°C
- COMBUSTION AIR	34.3	°C

AIR FLOW			RATIO
- COMBUSTION	939	Am³/min	
- PRIMARY	573	Am³/min	61 %
- SECONDARY	366	Am³/min	39 %

EFFICIENCY		
- INPUT/OUTPUT	60.1	%

STACK EMISSIONS

GAS		
- FLOW	1143	Sm³/min
- TEMPERATURE	231	°C
- MOISTURE	13.6	%
- OPACITY	35	%

CONTINUOUS DATA		
- O_2	12	%
- CO_2	8	%
- CO	78	ppm
- NO_x	235	ppm
- SO_2	152	ppm
- THC	2	ppm

ACID GAS		
- HCl	453	ppm

ORGANIC ANALYSIS		
- PCDD	299	ng/Sm³ *
- PCDF	298	ng/Sm³ *
- PCB	7005	ng/Sm³ *
- PAH	21801	ng/Sm³ *
- CB	9923	ng/Sm³ *
- CP	22501	ng/Sm³ *

PARTICULATE	55	mg/Sm³ *

METALS		
- Cd	89.6	ug/Sm³ *
- Pb	2039	ug/Sm³ *
- Cr	20.6	ug/Sm³ *
- Ni	8.0	ug/Sm³ *
- Hg	810	ug/Sm³ *
- Sb	112.1	ug/Sm³ *
- As	6.5	ug/Sm³ *
- Cu	91.2	ug/Sm³ *
- Zn	5122	ug/Sm³ *

Corrected to 12% CO_2

REFUSE

FEED RATE	9.5	tonne/hr
MOISTURE	34	%
CALORIFIC VALUE	2824	cal/g

ORGANIC ANALYSIS		
- PCDD	67	mg/tonne
- PCDF	4.1	mg/tonne
- PCB	120	mg/tonne
- PAH	1730	mg/tonne
- CB	93	mg/tonne
- CP	1830	mg/tonne

METALS		
- Cd	6.9	g/tonne
- Pb	763	g/tonne
- Cr	89	g/tonne
- Ni	24	g/tonne
- Hg	1.1	g/tonne
- Sb	43	g/tonne
- As	1.4	g/tonne
- Cu	43	g/tonne
- Zn	193	g/tonne

ASH

	INCINERATOR	BOILER	PRECIPITATOR	
ASH RATE	2303	42	124	Kg/h
ORGANIC ANALYSIS				
- PCDD	.16	43	605	ng/g
- PCDF	ND	25	233	ng/g
- PCB	ND	ND	12	ng/g
- PAH	155	33	122	ng/g
- CB	5	311	1381	ng/g
- CP	ND	68	1287	ng/g
METALS				
- Cd	3.6	135	514	ug/g
- Pb	1323	5511	10750	ug/g
- Cr	231	318	527	ug/g
- Ni	89	113	98	ug/g
- Hg	.0087	3.6	32	ug/g
- Sb	26	96	730	ug/g
- As	5.7	45	67	ug/g
- Cu	2245	541	946	ug/g
- Zn	2551	11100	33800	ug/g

FIGURE 10.10
POOR OPERATING CONDITIONS, DESIGN BURNING RATE,
LOW TEMPERATURE
PERFORMANCE TEST SUMMARY — PT03/04

OPERATING CONDITIONS

STEAM

- FLOW	28	tonne/h
- PRESSSURE	4323	kPa
- TEMPERATURE	322	°C

TEMPERATURES

- LOWER INCINERATOR	978	°C
- UPPER INCINERATOR	733	°C
- BOILER INLET	753	°C
- COMBUSTION AIR	32.1	°C

AIR FLOW

			RATIO
- COMBUSTION	547	Am³/min	
- PRIMARY	487	Am³/min	89 %
- SECONDARY	60	Am³/min	11 %

EFFICIENCY

- INPUT/OUTPUT	63.3	%

REFUSE

FEED RATE	8.7	tonne/hr
MOISTURE	33.2	%
CALORIFIC VALUE	2981	cal/g

ORGANIC ANALYSIS

- PCDD	23	mg/tonne
- PCDF	1.0	mg/tonne
- PCB	77	mg/tonne
- PAH	2810	mg/tonne
- CB	25	mg/tonne
- CP	803	mg/tonne

METALS

- Cd	2.0	g/tonne
- Pb	381	g/tonne
- Cr	51	g/tonne
- Ni	28	g/tonne
- Hg	.95	g/tonne
- Sb	9	g/tonne
- As	1.4	g/tonne
- Cu	595	g/tonne
- Zn	275	g/tonne
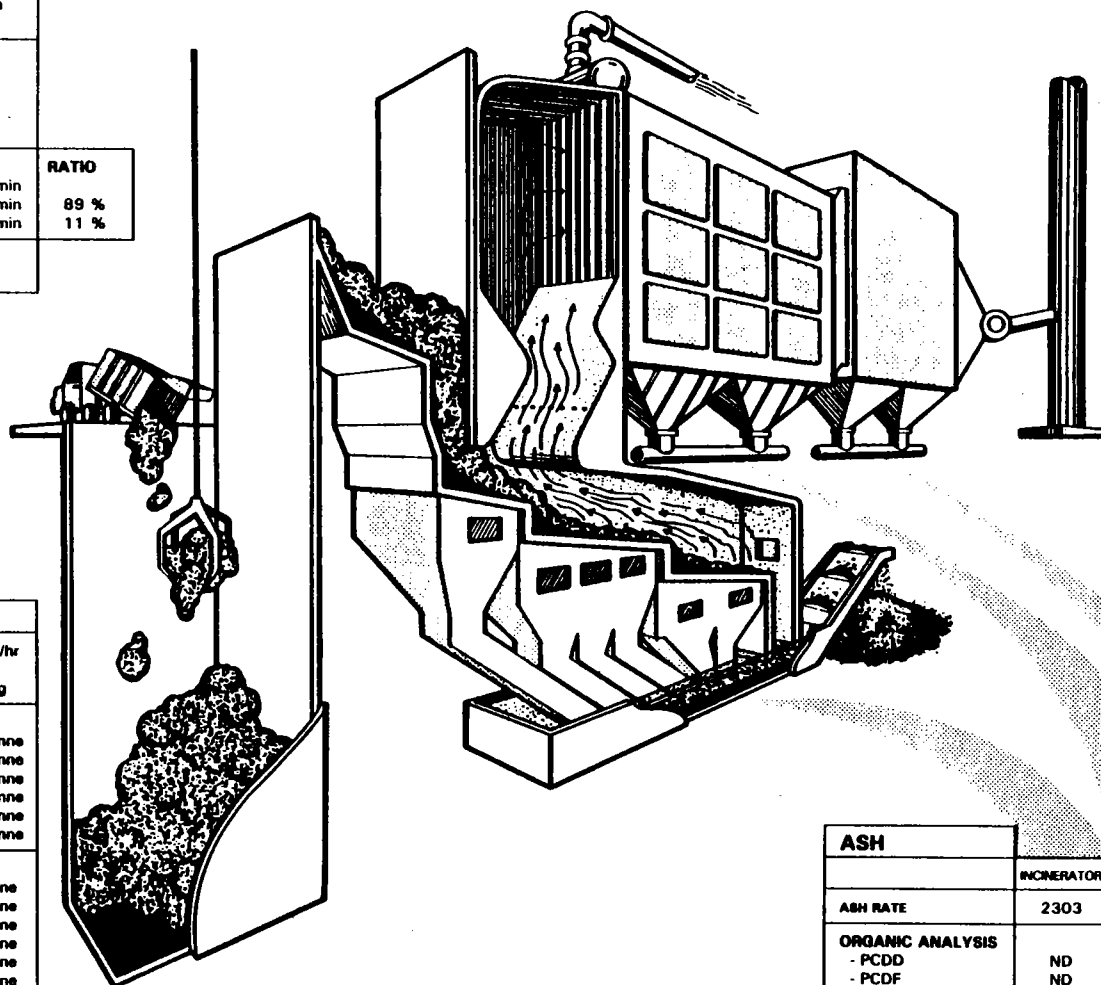
STACK EMISSIONS

GAS

- FLOW	1050	Sm³/min
- TEMPERATURE	230	°C
- MOISTURE	13.3	%
- OPACITY	35	%

CONTINUOUS DATA

- O_2	11	%
- CO_2	9	%
- CO	163	ppm
- NO_x	187	ppm
- SO_2	156	ppm
- THC	3	ppm

ACID GAS

- HCl	520	ppm

ORGANIC ANALYSIS

- PCDD	219	ng/Sm³*
- PCDF	306	ng/Sm³*
- PCB	1627	ng/Sm³*
- PAH	3146	ng/Sm³*
- CB	9520	ng/Sm³*
- CP	23737	ng/Sm³*

PARTICULATE

	62	mg/Sm³*

METALS

- Cd	75.7	ug/Sm³*
- Pb	2495	ug/Sm³*
- Cr	14.4	ug/Sm³*
- Ni	6.6	ug/Sm³*
- Hg	622	ug/Sm³*
- Sb	86.5	ug/Sm³*
- As	6.4	ug/Sm³*
- Cu	89.4	ug/Sm³*
- Zn	3429	ug/Sm³*

* Corrected to 12% CO_2

ASH

	INCINERATOR	BOILER	PRECIPITATOR	
ASH RATE	2303	42	124	Kg/h

ORGANIC ANALYSIS

	INCINERATOR	BOILER	PRECIPITATOR	
- PCDD	ND	51	945	ng/g
- PCDF	ND	17	260	ng/g
- PCB	ND	ND	24	ng/g
- PAH	320	69	331	ng/g
- CB	4	259	1515	ng/g
- CP	11	59	2968	ng/g

METALS

	INCINERATOR	BOILER	PRECIPITATOR	
- Cd	4.2	211	475	ug/g
- Pb	1638	8655	11800	ug/g
- Cr	171	235	348	ug/g
- Ni	72	109	108	ug/g
- Hg	.0038	2.9	41	ug/g
- Sb	10	265	328	ug/g
- As	7.7	54	46	ug/g
- Cu	1308	528	926	ug/g
- Zn	1172	12750	27300	ug/g

FIGURE 10.11
GOOD OPERATING CONDITIONS, DESIGN BURNING RATE
POOR AIR DISTRIBUTION
PERFORMANCE TEST SUMMARY — PT/14/15

Figure 10.12 : Furans - Poor Operation, Design Burn

DIOXIN EMISSION

QUEBEC MASS BURN 1986

Performance Tests

POOR — LOW TEMP.   POOR — POOR DIST.

FURAN EMISSION

QUEBEC MASS BURN 1986

Performance Tests

POOR — LOW TEMP.   POOR — POOR DIST.
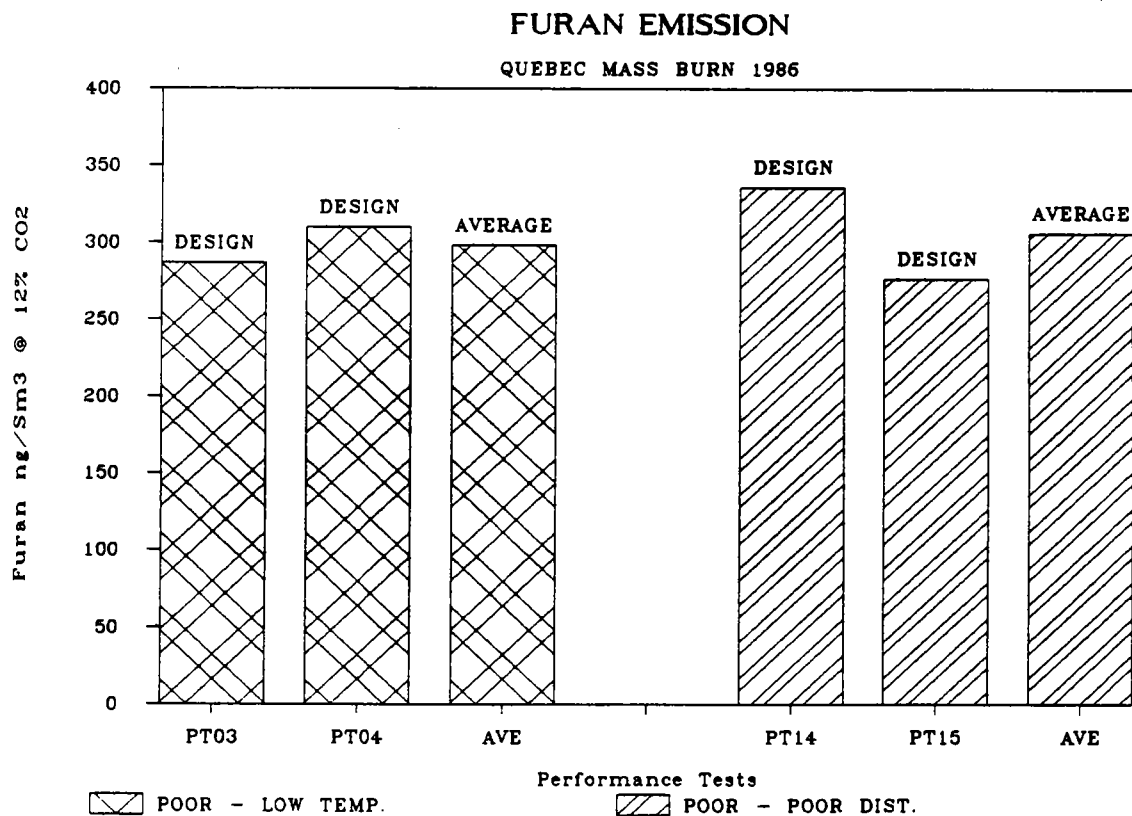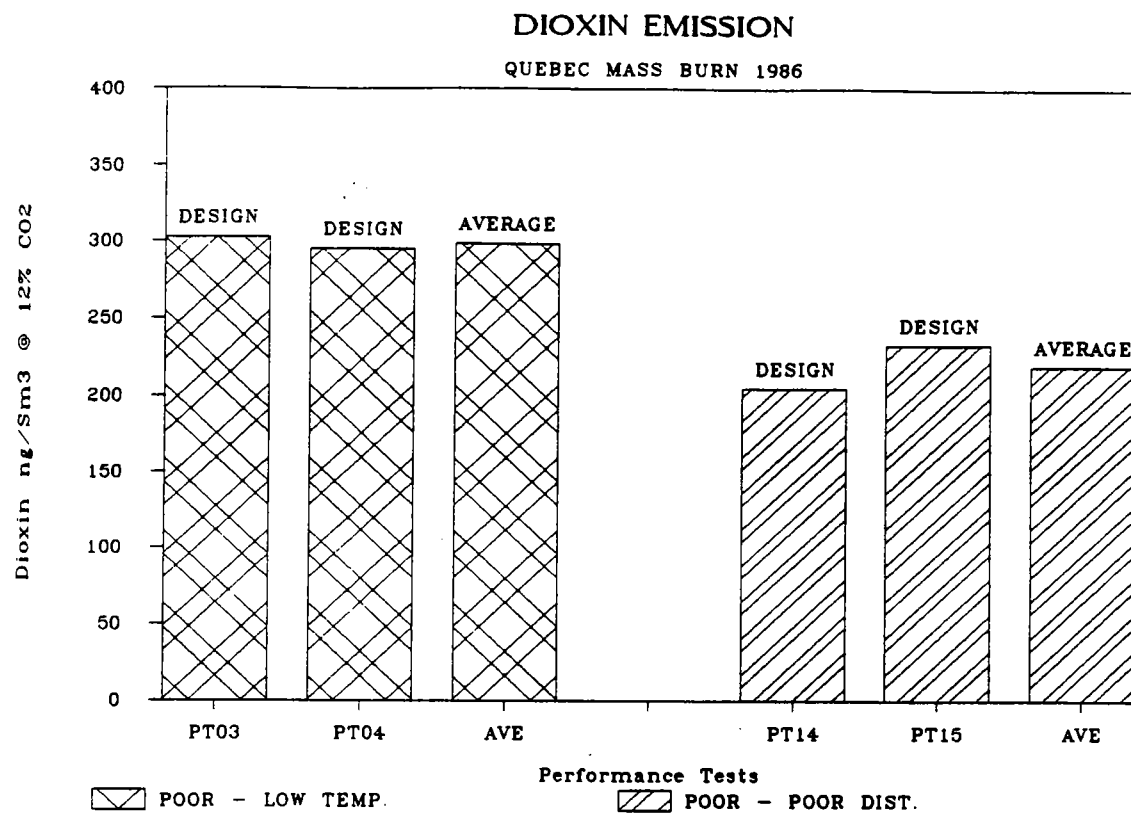
The low temperature test operating mode resulted in the highest dioxin levels, the test group average being 36% greater than the poor distribution test group average. The group average furan levels for low temperature and poor distribution tests were almost identical (i.e. within 3%).

The group averages for **other organics** during the poor operating condition tests were considerably higher than during the good operating condition at the design rate, with the exception of PAH and PCB concentrations found during the poor distribution tests. These were slightly lower. The following summarizes the group average results:

	Low Temperature Test Group Average	Poor Air Distribution Test Group Average
CP	4.4 x good level	4.6 x good level
PAH	5.5 x good level	0.8 x good level
CB	3.0 x good level	2.9 x good level
PCB	2.3 x good level	0.6 x good level

Each of the low temperature and the poor distribution tests experienced consistent and similar concentrations for CP and CB levels when compared with each other. PAH and PCB concentration test group averages were significantly higher under low temperature conditions compared to the poor distribution conditions.

Heavy Metals Stack Gas Results

The **lead** concentration in the stack gases under low temperature and poor air distribution test conditions varied significantly between tests. The concentrations were all relatively high as compared to the good operating condition at the design rate.

Mercury concentrations in the stack gases during the poor operating conditions were more consistent and similar to the good operating condition at the design rate. Levels were actually lower on average for the poor distribution test group.

These results are summarized below:

	Low Temperature Test Group Average	Poor Air Distribution Test Group Average
Lead	3.0 x good level	3.7 x good level
Mercury	1.2 x good level	0.9 x good level

Reference is made to Appendix A and Volume IV for other heavy metals results.

Other Test Results

The flue gas moisture levels between the poor operating condition tests were consistent (approximately 7% of the group average). The moisture content on a group average basis for the two poor operating conditions was virtually the same, both being less than the good operating condition design rate group average (14% lower).

Selected ash and refuse related test data are summarized in Table 10.18. Other results are presented in Appendix A and Volume IV.

Table 10.18
Ash and Refuse Results Under Poor Operating Conditions and Design Burning Rate.

| | LOW TEMPERATURE | | | GOOD OPERATING CONDITIONS | POOR DISTRIBUTION | | |
	PT-03	PT-04	Group Average	Group Average	Group Average	PT-14	PT-15
Boiler Ash							
Rate (% of refuse)	0.3	0.4	0.4	0.4	0.6	0.7	0.5
Carbon (% by wt.)	10.0	10.1	10.1	8.0	4.2	3.0	5.3
Precipitator Ash							
Rate (% of refuse)	1.3	1.5	1.5	0.6	1.4	1.5	1.2
Carbon (% by wt.)	5.8	6.3	6.1	17.3	8.3	10.5	6.0
Incinerator							
Wet Rate (% of refuse)	27.2	25.6	26.4	27.2	23.8	21.4	26.2
Carbon (% by wt.)	2.3	6.0	4.2	5.8	4.2	1.9	6.4
Refuse							
Feed Rate (tonne/hr)	10.1	9.0	9.6	8.9	8.7	8.4	9.0
Moisture (% by wt.)	32.2	36.3	34.3	35.3	33.2	31.2	35.1

Boiler ash rates during the poor operating condition tests were similar to the good operating condition at the design rate. The carbon content group average for the low temperature tests was about 26% higher than for the good operating condition at the design rate while the carbon content for the poor distribution test group was 1.9 times lower.

The most noticeable difference with ash data was the relatively high **precipitator ash** rate that occurred during all of the poor operating condition tests. For poor operating condition tests, the precipitator ash rate was at least twice the good operating condition at the design rate. An unexpected result was that the group average carbon content in the precipitator ash during both poor operating conditions appeared to be lower than for the good operating condition at the design rate. As previously indicated in sub-section 10.2.2, the apparently high carbon content for the good operating condition at the design

rate was inflated due to one of the tests, PT-06. The other two tests showed similar carbon content as experienced during the poor operating condition tests.

The **incinerator ash** rate during the low temperature and poor distribution tests was slightly less than experienced during good operating conditions at the design rate on the basis of group averages. All were relatively low, 20 to 40% being typical for this technology. Carbon content in the incinerator bottom ash was relatively low during the four poor tests, with similar variation between tests as for other operating conditions. The group average for both poor operating conditions was virtually the same, being lower than for the good operating condition at the design rate. While this data may not have been representative as previously indicated, the apparently better ash quality for these poor operating conditions was not that surprising. These poor operating modes are often preferred by operators since they involve high primary air rates and therefore result in reduction of visible "unburnables" in the ash.

The **refuse** feed rate during the low temperature tests was about 8% higher than during the good operating condition at the design rate. The poor distribution test group average was within 2%. The moisture content in the refuse was within 6% on the basis of group averages.

10.4 SUMMARY COMPARISON OF TEST GROUP AVERAGE

This section summarizes the group averages developed in the previous sections of this chapter. Significant differences in process and sampling program results between test groups are discussed.

Reference is made to Chapter 11.0 for a review of correlations that were developed from individual test averages.

Process Parameter Results

Reference is made to the process parameters summary, Table 10.19, for the group averages.

These results demonstrate that during the test program, the incinerator was operated over a wide range of operating conditions. The key process parameters that were utilized to obtain the five distinct operating conditions covered a wide range of values on a group average basis as follows:

- steam rate ranged from 71% to 114% of the design rate,
- radiation chamber temperatures varied within 187 C degrees, and
- excess air levels ranged between 78% and 140%.

Input/output efficiencies remained relatively high on average under all operating conditions. The lowest efficiency, 60.1%, was experienced during the low temperature poor operating mode. The

Table 10.19
Group Averages for the Key Process Parameters

| | GOOD OPERATING CONDITIONS BURNING RATE | | | POOR OPERATING CONDITIO DESIGN BURN RATE | |
	LOW	DESIGN	HIGH	LOW TEMP.	POOR DIST.
Seam Rate (tonne/hr)	20.0	28.0	31.8	28.0	28.4
Primary Air (% of total)	58	65	55	61	89
Secondary Air (% of total)	42	35	45	39	11
Radiation Chamber Temp. (deg C)	864	1012	1046	859	978
Boiler Inlet Temperature (deg C)	696	805	823	712	754
Excess Air Level (%)	140	78	84	130	113
Input/Output Efficiency (%)	61.6	63.7	66.2	60.1	63.3
Steaming Ratio (kgs/kgr)	3.1	3.1	3.3	3.0	3.3
Flue Gas Flow Rate (Sm3/min)	886	875	965	1143	1051

highest group average value, 66.2%, occurred under good operating conditions at the high burning rate.

Flue gas flow rate group averages varied considerably. The maximum was represented by the low temperature poor operating condition and was 31% above the low rate experienced during the good operating condition at design rate.

Continuous Gas Data

Table 10.20 summarizes the continuous gas monitoring results.

The lowest CO group average (24 ppm) occurred during the low rate test while the highest (163 ppm) occurred during the poor distribution test. The differences in CO levels between each operating condition are shown graphically in Figure 10.13. Typically, CO levels below 250 ppm represent reasonable combustion efficiency, although modern facilities can be expected to achieve CO levels below 50 ppm on average. Only the poor distribution operating condition experienced relatively high average levels of CO. In setting up the various operating conditions, CO was used as one of the primary indicators of the type of operation that was being achieved, both on a short-term basis and on a test average basis. Reference is made to Chapter 11 for a review of CO correlations with process parameters and other emissions.
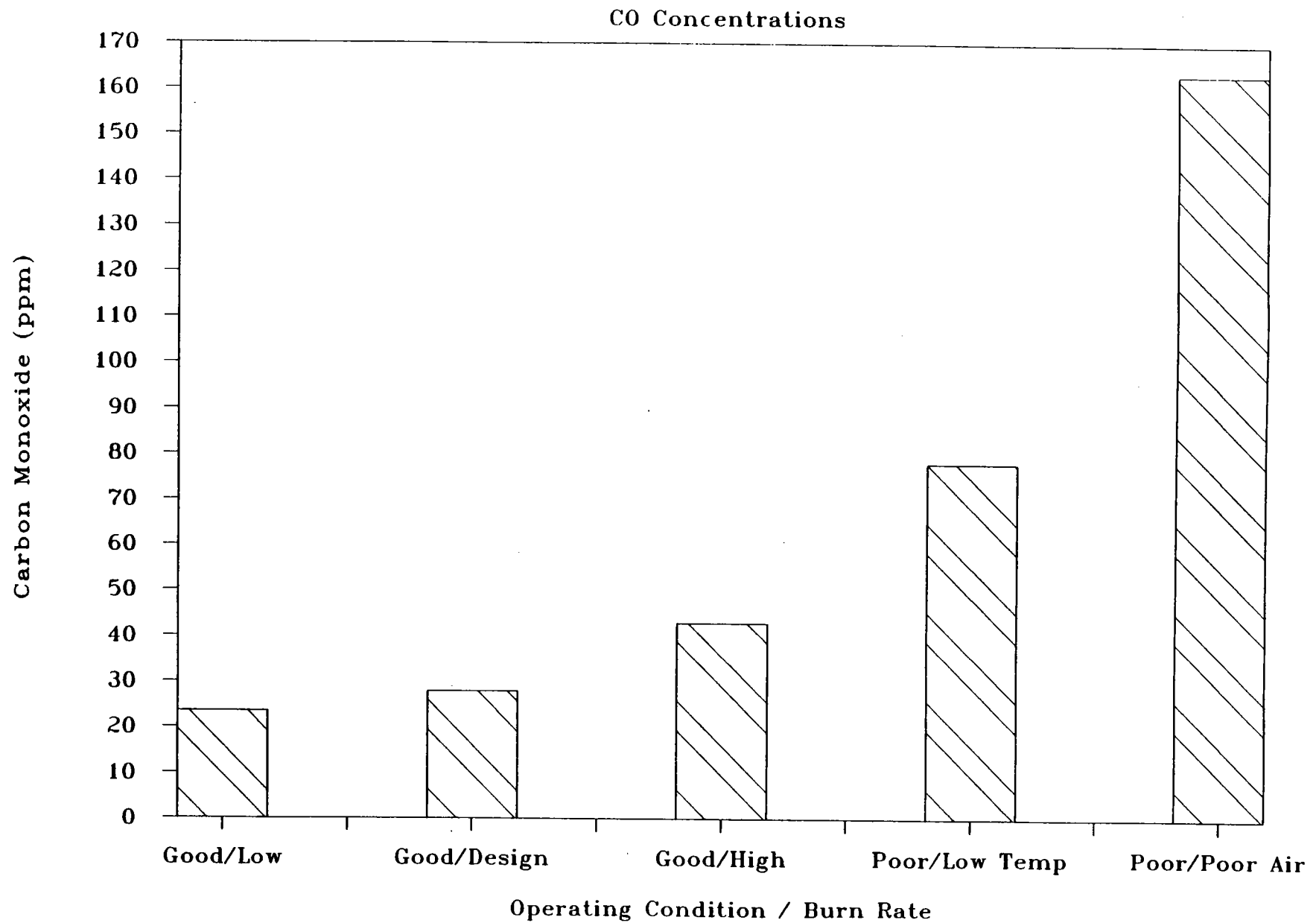
Figure 10.13 Group Averages

CO Concentrations

Table 10.20
Group Averages for the Continuous Gas Monitoring Results

| | GOOD CONDITIONS BURNING RATE | | | POOR CONDITIONS DESIGN BURN RATE | |
	LOW	DESIGN	HIGH	LOW TEMP.	POOR DIST.
Carbon Monoxide (ppm)	23.5	27.9	43	78.0	163.4
Total Hydrocarbons					
cold (ppm)	2.3	1.8	1.7	2.1	3.1
hot (ppm)	5.1	N/A	N/A	4.3	N/A
Nitrogen Oxides (ppm)	205	180	194	235	187
Hydrogen Chloride (ppm)	499	452	441	N/A	521
Sulfur Oxides (ppm)	181	196	160	153	157
Opacity (%)	29	33	32.5	35.3	35.4

Note: Values corrected to 12% CO2

Total hydrocarbons showed little variation between test groups, all being quite low. For modern incinerator facilities, hydrocarbon concentrations below 50 ppm are anticipated, levels below 10 ppm being common.

Maintaining the hot hydrocarbon analyzer in service was difficult during the test program as demonstrated by the absence of 3 of the 5 averages from the data.

Group averages for **nitrogen oxides** and **sulfur oxides** varied little between testing modes. The maximum group average was approximately 30% greater than the minimum in both cases. Maximum and minimum group averages for nitrogen oxides during the three good operating condition test groups varied by less than 14%. The highest group average occurred during the low temperature poor operating conditions. Further review of the effects of operating characteristics on nitrogen oxide results is presented in Chapter 11.

Hydrogen chloride group averages were consistent between test groups. The maximum group average was 18% above the minimum. Individual test results showed a more significant variation (i.e. 366 ppm to 594 ppm), the maximum being 62% above the minimum. Reference is made to Appendix A and Volume IV for data on the short-term peaks (i.e. 5-minute averages).

As with sulfur oxide concentrations, hydrogen chloride concentrations showed no correlation with operating conditions, apparently being solely a function of refuse content.

The maximum group average for **opacity** was 22% above the minimum, the maximum occurring for the poor distribution operating condition, the minimum during the low burning rate, good operating condition. This variation was not significant. As indicated previously, this instrument was inconsistent as an indicator of higher or lower particulate concentration.

Stack Sampling Train Results

Stack sampling train results are summarized in Table 10.21.

Table 10.21
Group Averages for the Stack Sampling Results

| | GOOD CONDITIONS BURNING RATE | | | POOR CONDITIONS DESIGN BURN RATE | |
	LOW	DESIGN	HIGH	LOW TEMP.	POOR DIST.
Total Particulates (mg/Sm3)	26.3	22.3	35.6	54.9	62.5
Hydrogen Chloride (ppm)	505	363	381	464	398
Dioxins (ng/Sm3)	52.6	18.8	55.4	298.5	218.9
Furans (ng/Sm3)	114.5	44.5	100.7	298.3	306.4
Chloro-Phenols (ug/Sm3)	9.5	5.1	8.0	22.5	23.7
PAHs (ug/Sm3)	7.1	4.0	5.4	21.9	3.2
Chlorobenzene (ug/Sm3)	3.5	3.3	4.4	9.9	9.5
PCBs (ug/Sm3)	4.3	3.0	4.9	7.0	1.7
Lead (ng/Sm3)	978	673	1599	2039	2495
Mercury (ng/Sm3)	783	704	872	810	623
Flue Gas Moisture (% by vol.)	12.9	15.6	15.0	13.6	13.3
Particle Size (% below 2.5 um)	33	29	24	26	24

Note: Values corrected to 12% CO_2

All particulate concentrations were relatively low, particularly under good operating conditions. Typically, modern incineration technology with efficient precipitator equipment can be expected to achieve particulate concentrations between 20 and 70 mg/Sm^3. Thus, considering that the incinerator tested utilized a 2-stage precipitator that had been in operation for 11 years, these results were

surprisingly low. The lowest group average occurred for the good operating condition at the design rate. The highest concentration occurred for the poor distribution operating condition, being 2.8 times higher. The difference of the group average concentration of particulates for each operating condition are shown graphically in Figure 10.14. Reference is made to Chapter 11 for a review of particulate correlations with process parameters and other emissions.

Hydrogen chloride concentrations as determined by the stack sampling trains varied by approximately 40% between maximum and minimum group averages as compared to the 18% difference found using the continuous gas monitor. As with the continuous gas analyzer results, there was no correlation of the chloride concentration to the operating conditions. There was also no consistency between the two sampling methods with respect to which method showed the higher results. The continuous gas analyzer showed group averages being higher for three operating conditions, lower for the other two when compared to the stack sampling train results.

Organic Train Stack Gas Results

Dioxin and **furan** stack gas concentration group average results were the lowest for the good operating condition design rate tests (below 55 ng/Sm^3). For dioxin, the highest (299 ng/Sm^3) occurred during the low temperature, poor operating condition tests. In the case of furans, the highest occurred during the poor distribution tests. Figure 10.15 shows graphically the group average concentrations of dioxins and furans for each operating condition. Further comparisons between the design burning rate, good operating condition and poor operating conditions are presented in sub-section 10.3.

Reference is made to Chapter 11 for dioxin and furan correlations with process parameters and other emissions.

Correlation of **CO** concentrations with **dioxin** and **furans** in the stack gases is immediately apparent from the group average results. The good operating condition tests experienced the lowest concentrations of CO, dioxin and furans. The highest dioxin and furan concentration corresponded to one of the two poor operating conditions as did the highest CO concentrations. For the two poor operating conditions, the highest CO group average was associated with the poor distribution condition. The low temperature condition experienced the higher group average dioxin concentration. Furan group average concentrations were similar for both poor operating conditions, the poor distribution condition being less than 3% higher than the low temperature condition.

Comparing the **CO** and **dioxin** variation between the group averages of good and poor operating conditions, the range of CO concentrations (the maximum was 7 times the minimum) was half the variation experienced with the dioxin concentrations (the maximum was 16 times the minimum). The furan variation was similar to the variation experienced between the maximum and minimum for CO (i.e. its maximum was 7 times greater than its minimum). Considering only the good operating condition group averages, the range of CO, dioxin, and furan concentrations experienced was significantly less, as indicated by the following summary:

● Dioxin concentrations maximum was 2.9 times minimum

● Furan concentrations maximum was 2.6 times minimum
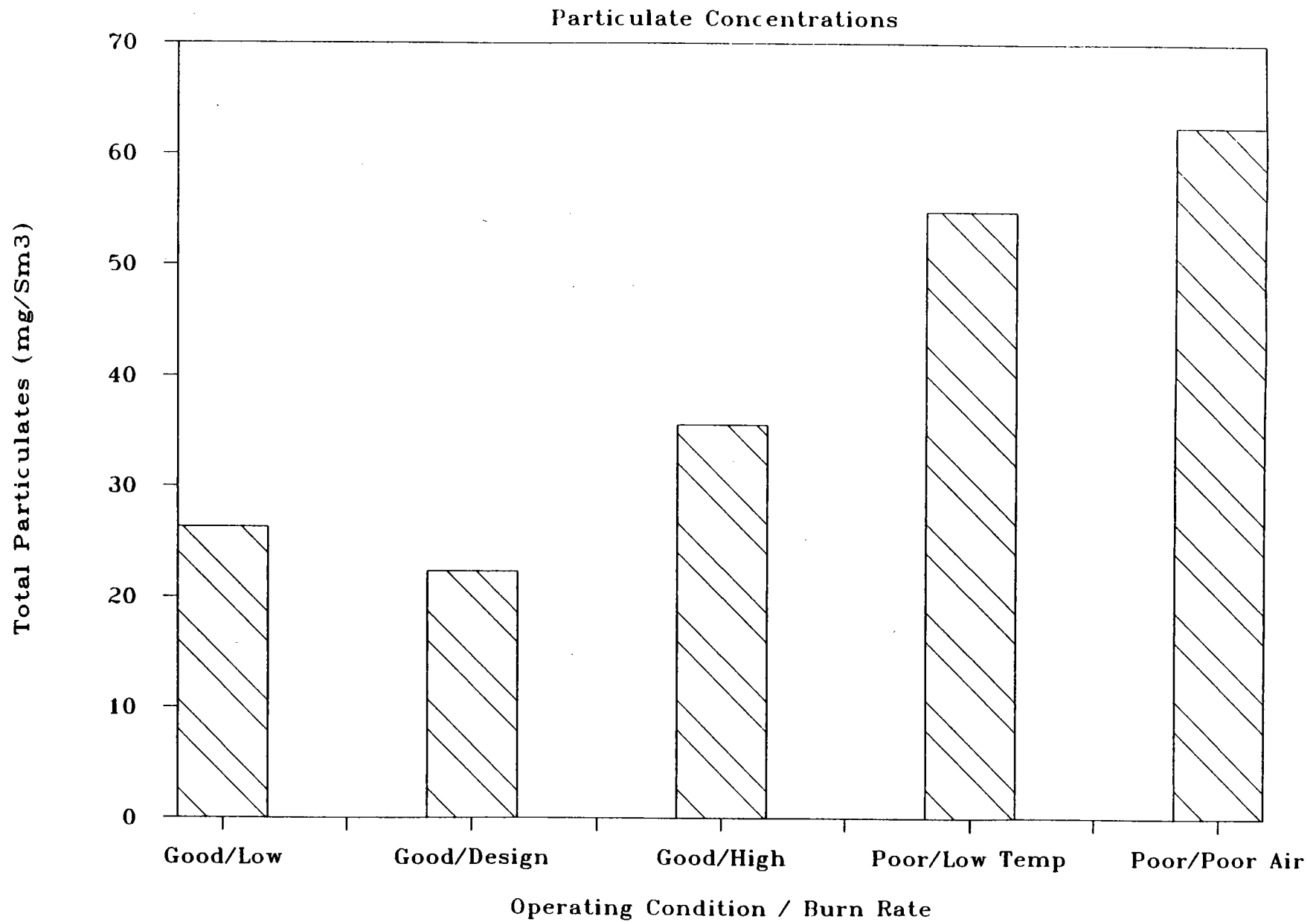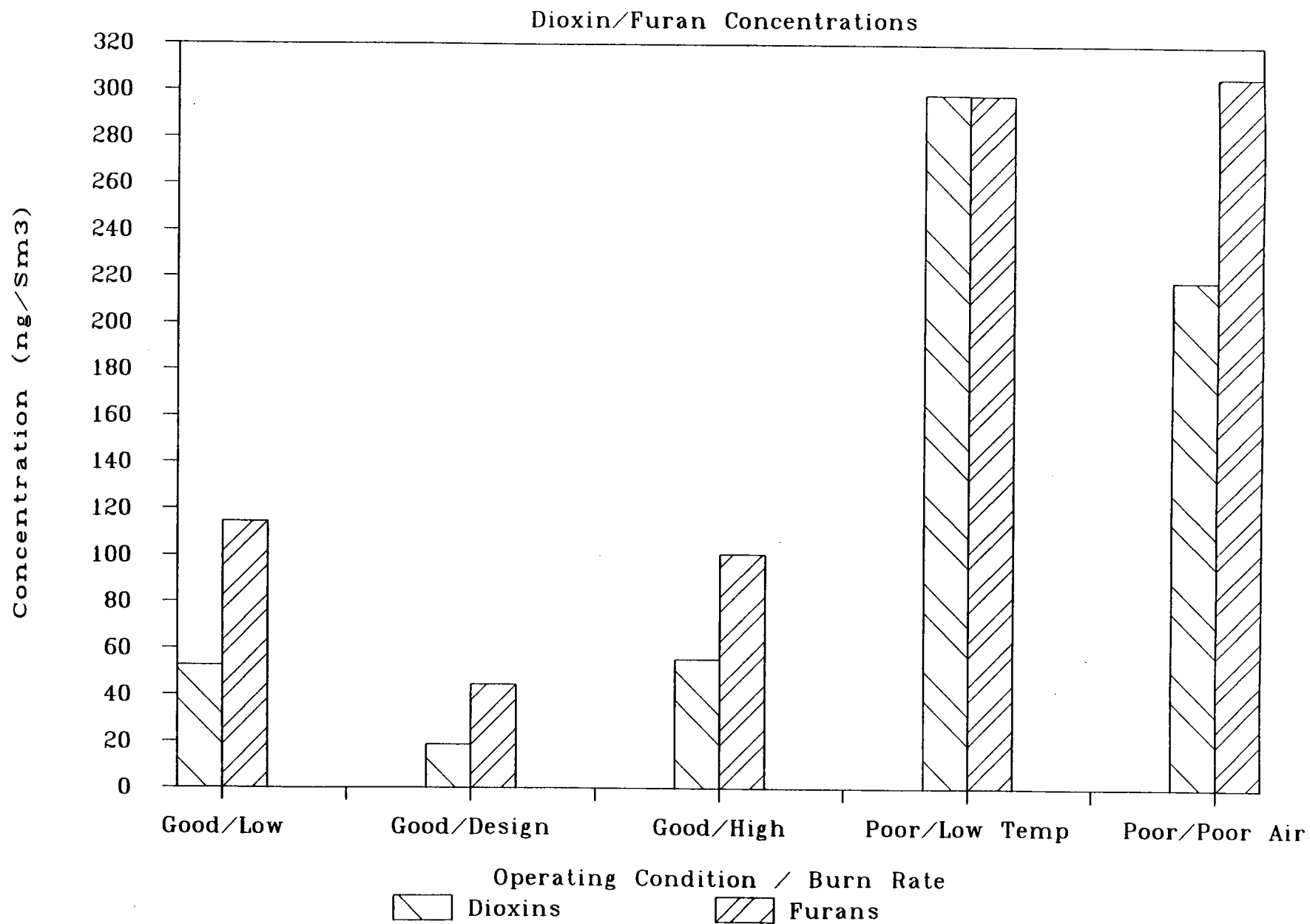
Figure 10.14 Group Averages

Particulate Concentrations

Chart: Total Particulates (mg/Sm3) vs Operating Condition / Burn Rate

- Good/Low: ~26
- Good/Design: ~22
- Good/High: ~35
- Poor/Low Temp: ~54
- Poor/Poor Air: ~62

Figure 10.15 Group Averages

Dioxin/Furan Concentrations

Operating Condition / Burn Rate

- Carbon monoxide concentrations maximum was 1.8 times minimum

As with the good versus poor operating condition overall averages, the variations of dioxin and furans for the good operating condition groups alone were greater than the CO group average variation.

The dioxin emissions for the low and high burning rates were similar at 52.6 and 55.4 ng/Sm^3 corrected to 12% CO_2; the design rate good operating condition was even lower at 18.8 ng/Sm^3 corrected to 12% CO_2. A similar trend occurred in the case of furan stack gas concentrations, the low and high rate operating condition concentrations being similar (average 107.6 ng/Sm^3), the design rate concentrations being less than half at 44.5 ng/Sm^3 corrected to 12% CO_2.

Comparison with PEI NITEP Results

The group averages for dioxin stack gas concentrations under the three good operating conditions were all relatively low, below 55 ng/Sm^3. These values all compare favorably with the concentrations experienced during the PEI NITEP two stage combustion program. The following summarizes the group average results of the PEI test program for dioxin and furan concentrations in the stack gases in ng/Nm^3 corrected to 12% CO_2.

	Dioxin ng/Sm^3		Furan ng/Sm^3	
	PEI	Quebec	PEI	Quebec
Normal Operating Condition	107	19	143	44
Other Operating Conditions	62 - 123	11 - 303	95 - 156	32 - 336

It is noted that the PEI test were all undertaken at the same burning rate. It is also interesting to note that the PEI tests experienced somewhat higher CO concentrations, the group average being 67 ppm corrected to 12% CO_2 during normal operation with a group average range of 33 to 67 ppm under all operating conditions tested.

Review of Stack Gas Dioxin/Furan Homologues

Table 10.22 summarizes the stack gas concentrations of dioxin/furan homologues on a group average basis. Homologue data for each individual test are presented in Volume IV. The good operating condition at the design burning rate resulted in the lowest dioxin group average for all homologues, the highest group average levels occurring with the low temperature poor operating condition test group average. The results also indicated that both the low temperature and poor distribution test group averages for all homologues were all higher than any of the good operating condition group averages.

Table 10.22
Group Averages for Dioxin/Furan Homologues

| Homologue | GOOD CONDITIONS BURNING RATE | | | POOR CONDITIONS DESIGN BURN RATE | |
	LOW	DESIGN	HIGH	LOW TEMP.	POOR DIST.
T4CDD	3.9	0.6*	3.8	15.8	1.5
P5CDD	5.4	1.1*	7.5	33.9	20.3
H6CDD	10.3	2.9*	19.0	77.0	51.1
H7CDD	15.2	6.1*	27.7	98.0	68.6
OCDD	17.7	8.1*	33.4	73.9	67.5
Total PCDD	52.6	18.8*	91.4	298.5	218.9
T4CDF	39.1	18.7*	42.0	89.1	103.6
P5CDF	39.9	15.0*	34.9	98.9	108.0
H6CDF	22.5	7.8*	18.5	70.6	62.2
H7CDF	12.5	2.9*	10.9	37.1	30.2
OCDF	0.5	0.1*	0.4	2.8	2.4
Total PCDF	114.5	44.5*	106.6	298.3	306.4

* indicates the lowest value

Considering the furan results, again the lowest group average for all homologues occurred during the good operating condition mode at the design rate. As was the case for the dioxin results, all homologue

group average values experienced during the poor test groups were higher than any group average values found during the good operating condition tests. The only difference noted between the dioxin and furan results was that for the furan results, three of the maximum homologue group average values occurred for the low temperature operating condition while the other two occurred for the poor distribution tests.

These homologue results are presented graphically in Figure 10.16. The higher molecular weight homologues are in greater concentrations. This distribution is consistent with the results of the other testing programs, PEI and Flakt.

Figure 10.16 : Dioxin and Furan Homologues

STACK GAS DIOXIN

HOMOLOGUES

DIOXIN CONCENTRATION @12% CO2

OPERATING CONDITIONS

T4CDD P5CDD H6CDD H7CDD OCDD

STACK GAS FURAN

HOMOLOGUES

FURAN CONCENTRATION @12% CO2

OPERATING CONDITIONS

T4CDF P5CDF H6CDF H7CDF OCDF
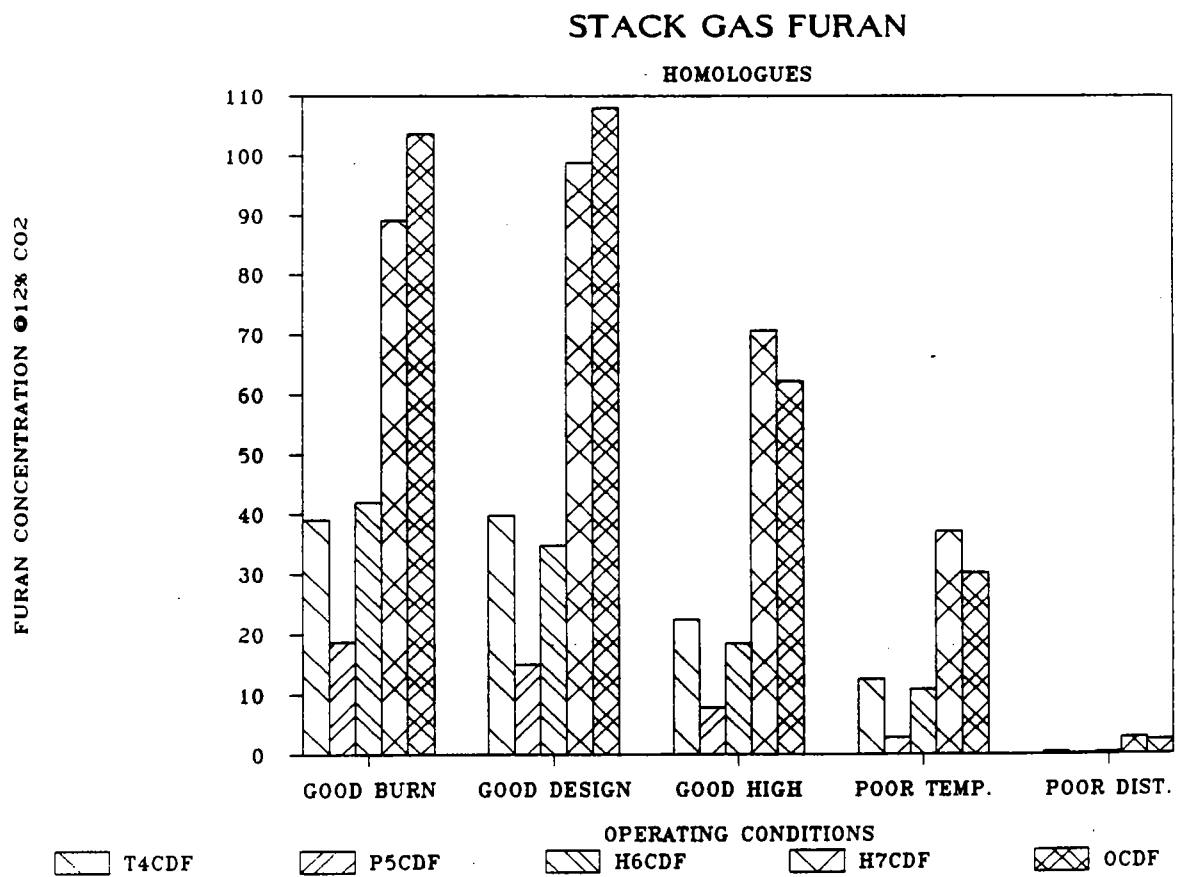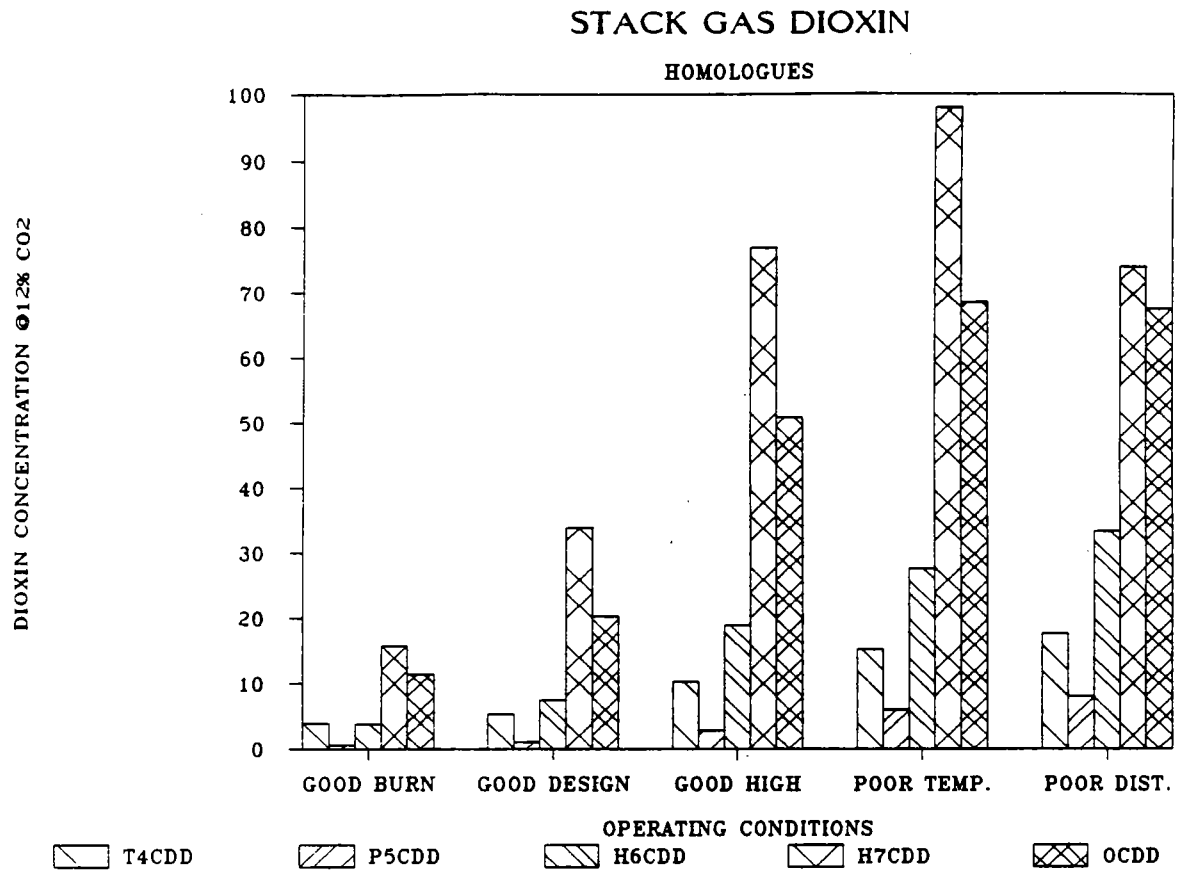
Review of Other Organics Results

Test group averages for CP and CB concentrations were lowest (5.1 and 3.3 ug/Sm^3, respectively) for the good operating condition at the design rate and highest (24 at 10 ug/Sm^3, respectively) for the poor operating condition tests. The PCB and PAH concentrations however were lowest for the poor distribution test group (3.2 at 1.7 ug/Sm^3, respectively).

The following table summarizes the range experienced between group averages for these organics:

> CP   The maximum was 4.6 times the minimum
> CB   The maximum was 3.0 times the minimum
> PCB   The maximum was 4.1 times the minimum
> PAH   The maximum was 6.8 times the minimum

A comparison of these organics with the NITEP PEI results indicated that the concentrations for CP, CB and PAH were similar, although generally lower for PEI. The PCB group averages during the PEI tests were 2 to 120 times lower depending on the operating condition being compared. A comparison of the concentrations during good operation at the design burn rate with the PEI NITEP results under normal operation indicated that PEI results were approximately 4 times lower for PCB and 15% lower for CP, but were 30% higher for CB and 75% higher for PAH stack gas concentrations. The following summarizes the PEI results.

Table of Trace Organic Concentrations
(ug/Sm^3 corrected to 12% CO_2)

| | Normal Operation | | Other | |
	PEI	Quebec	PEI	Quebec
PCB	0.8	3.0	0.06 to 0.8	0.8 to 10.2
PAH	7.0	4.0	6.7 to 12.5	2.6 to 31.7
CP	4.3	5.1	2.7 to 6.6	4.0 to 26.1
CB	4.3	3.3	3.2 to 4.9	2.4 to 10.4

Reference is made to Chapter 11 for the correlations that resulted between these organics and other emissions and process parameters.

Heavy Metals Stack Gas Results

Lead stack gas concentration group averages varied considerably between operating conditions. The highest group average experienced was with the poor distribution tests, being 3.7 times the lowest which occurred with the good operating condition, design rate group.

The **mercury** stack gas concentration group averages showed less variation than the lead results. The low group average occurred during the poor distribution operating conditions, the high during the good operating condition, high rate test group. The maximum was 40% higher than the minimum as compared to the 3.7 times difference experienced with the lead results.

Reference is made to Chapter 11 for the correlations that resulted between the metals concentrations in the stack gases and other emissions and process parameters. Reference is also made to Appendix A and Volume IV for other heavy metals results.

Other Test Results

Flue gas moisture was relatively consistent for all test groups, the maximum group average of 15.6% by volume being 21% above the minimum of 12.9%. In comparison, the group average moisture content ranged from 11 to 18% over the various operating conditions tested at PEI.

Selected ash and refuse related group averages are summarized in Table 10.23. Other results are presented in Volume IV. Correlations are presented in Chapter 11.

Table 10.23
Group Average for Ash and Refuse

| | GOOD CONDITIONS BURNING RATE | | | POOR CONDITIONS DESIGN BURN RATE | |
	LOW	DESIGN	HIGH	LOW TEMP.	POOR DIST.
Boiler Ash					
Rate (% of refuse)	0.5	0.4	0.5	0.4	0.6
Carbon (% by wt.)	4.7	8.0	22.8	10.1	4.2
Precipitator Ash					
Rate (% of refuse)	0.7	0.6	0.9	1.4	1.4
Carbon (% by wt.)	6.9	17.3	10.6	6.1	8.3
Incinerator Bottom Ash					
Wet Rate (% of refuse)	25.4	27.2	21.8	26.4	23.8
Carbon (% by wt.)	2.6	5.8	5.2	4.2	4.2
Refuse					
Feed Rate (tonne/hr)	6.5	8.9	9.7	9.6	8.7
Moisture (% by wt.)	36.9	35.3	34.8	34.3	33.2

The group average **boiler ash** rates were consistent, with no significant variation between operating conditions. The carbon content however varied considerably; the high burning rate showed the highest

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level. While higher flue gas flow rates and reduced retention might explain these results, the results of the poor distribution test group were lowest. The poor air distribution condition actually experienced higher flue gas flow rates. These results do not seem to accurately reflect the variation that actually occurred between the various operating conditions.

The group average **precipitator ash** rates appear to be more representative of the various operating conditions; the high flue gas flow rate tests experienced the highest particulate carryover rates. Both poor operating conditions experienced more than twice the particulate carryover rate experienced during the good operating condition at the design rate. The carbon content results were somewhat surprising in that the poor operating conditions showed relatively lower carbon content compared to the good operating conditions at the design burning rate which experienced the highest carbon content level. This variation in carbon content was not even closely comparable with the boiler fly ash carbon content results and therefore again must be reviewed with a certain level of skepticism.

The group average **incinerator ash** rates for the various operating conditions were surprisingly consistent considering the wide range of operating conditions under which the incinerator was tested. These rates at first glance seemed to confirm the visual observations that the bottom ash quality improves as underfire air rates increase. Although the rates are so similar for all tests, it is difficult to establish any significant conclusion concerning variation of bottom ash rates with varying operating conditions. The ash rates are all relatively low, 20 to 40% by wet weight being anticipated for this technology.

The group average **carbon** content in the **incinerator ash** was also surprisingly consistent between operating conditions; all showed relatively low levels. On an individual test result basis, the variation between the maximum and minimum was a factor of 2. Considering the difficulty in obtaining representative samples for the carbon content of the bottom ash, again these results should be considered with a certain level of skepticism. Carbon content in the bottom ash is typically specified at less than 5% by weight, by manufacturers of similar incineration equipment as that tested in this program.

The group average **refuse feed** rates covered a wide range over the test program from 6.5 to 9.7 tonne/hr, as intended. The maximum was 49% above the minimum. This intended range corresponds to the range in steam production. The maximum group average steam rate was 59% above the minimum (see Table 10.19).

10.5 MISCELLANEOUS RESULTS

10.5.1 Particle Size Distribution

Determination of the particle size distribution was carried out at the precipitator outlet at a sampling point test represented average flue gas velocity. Tables 10.24A and B present the individual test results. There did not appear to be any relationship between the particle size distribution and the

PARTICLE SIZE		PT-01	PT-02	PT-03	PT-04	PT-05	PT-06	PT-07	PT-09	PT-10	PT-11	PT-12	PT-13	PT-14	PT-15
< 2.5 (um)	%	46	35	22	30	40	24	36	11	37	23	23	21	28	20
< 5.0 (um)	%	52	64	33	38	45	31	42	13	41	27	35	32	32	27
< 7.5 (um)	%	57	74	42	42	50	32	45	19	41	29	43	38	35	36
< 10.0 (um)	%	61	82	48	44	52	33	48	22	42	30	46	41	36	42

TABLE 10.24 B
PARTICLE SIZE DISTRIBUTION
BY OPERATING GROUP

PARTICLE SIZE		GOOD OPERATION LOW BURNING RATE			GOOD OPERATION DESIGN BURNING RATE			GOOD OPERATION HIGH BURNING RATE		POOR OPERATION DESIGN BURNING RATE LOW TEMPERATURE		POOR OPERATION DESIGN BURNING RATE POOR AIR DISTRIBUTION	
		PT-02	PT-10	PT-11	PT-05	PT-06	PT-12	PT-07	PT-09	PT-03	PT-04	PT-14	PT-15
< 2.5 (um)	%	35	37	23	40	24	23	36	11	22	30	28	20
< 5.0 (um)	%	64	41	27	45	31	35	42	13	33	38	32	27
< 7.5 (um)	%	74	41	29	50	32	43	45	19	42	42	35	36
< 10.0 (um)	%	82	42	30	52	33	46	48	22	48	44	36	42

operating mode. The results ranged between 11% and 40% for particles 2.5 m and 22% to 82% for particles smaller than 10 m. However, no trends between operating modes were apparent. On average for the test program, 28% of the particles were smaller than 2.5 m and 44% smaller than 10 m.

Particle size sampling procedures are described in Section 5.5.6.

10.5.2 Multi-Sampling of Refuse

To assess the variability in refuse composition and the analytical reproducibility of results, triplicate sampling was carried out during PT-14. The sampling period was divided into three equal time intervals. Shredded refuse from each interval was put into a separate pile following the procedures described in sub-section 5.2.2. Five samples were taken from each of the three refuse piles. Each sample was dried and processed as detailed in sub-section 6.3.1. As shown in Figure 10.17, for V/P/HHV analysis, one of the five samples (per pile) was analyzed as a whole (Subsample 1) and a second sample was split and analyzed in duplicate (Subsamples 2 and 3). For the metals analysis, one sample was analyzed as a whole (Subsample 1) while a second sample was divided in three and analyzed in triplicate (Subsamples 2,3, and 4). Lastly, for analysis of trace organics, one sample was analyzed in triplicate (Subsamples 1,2, and 3). Tables 10.25 to 10.27 present the analytical results for each sub-sample.

As presented in Table 10.25, the HHV or calorific value of the refuse sample (laboratory analysis) ranged from 6336 BTU/lb to 7686 BTU/lb with an average of 6962 BTU/lb and a standard deviation of 516 BTU/lb.

The results for trace organics, as presented in Table 10.26, showed little variation between sub-samples within each sample group (with the exception of PCB), but a large variation between Samples A,B, and C, indicating a change in refuse composition over time. A similar trend resulted from the metals analysis, as shown in Table 10.27. However, lead was the exception.

The metals analysis also indicated the degree of homogeneity within each refuse pile. Two separate samples were analyzed from each refuse pile, one sample analyzed as a whole (Subsample 1) and a second sample divided into three and analyzed separately (Subsamples 2,3, and 4). As seen in Table 10.27, the results for Subsample 1 were within the same order of magnitude as the triplicate sample of the same group.

The multi-sampled revealed the variability of refuse composition within a sample and provided a good assessment of the sample's homogeneity. As shown in Table 10.27, variation between subsamples (within each sample) were on the whole, slight, indicating that the samples taken were fairly homogeneous.

The test also confirmed that good repeatability was possible by the analytical procedures.
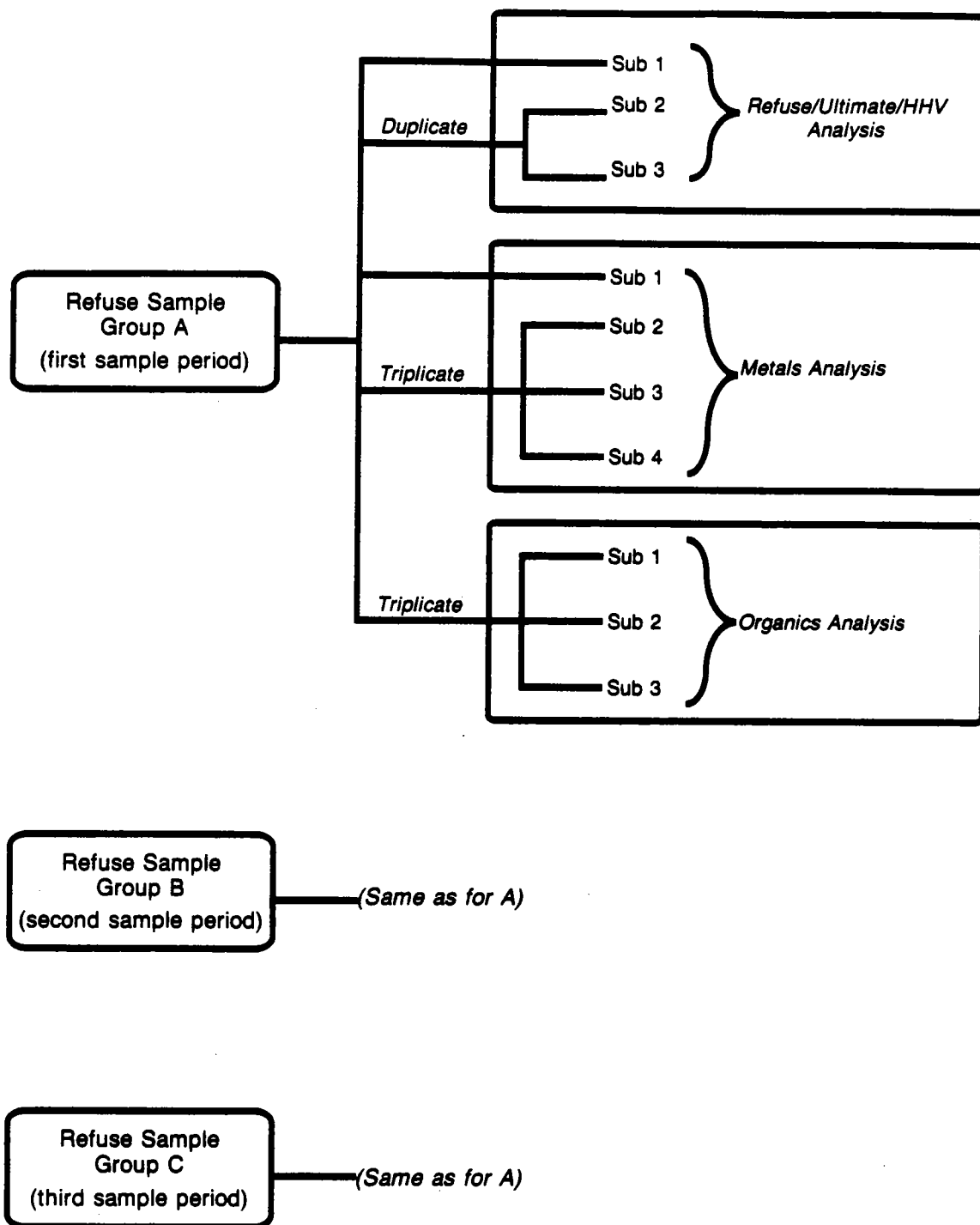
Refuse Sample
Group A
(first sample period)

Duplicate

Sub 1
Sub 2
Sub 3

Refuse/Ultimate/HHV
Analysis

Triplicate

Sub 1
Sub 2
Sub 3
Sub 4

Metals Analysis

Triplicate

Sub 1
Sub 2
Sub 3

Organics Analysis

Refuse Sample
Group B
(second sample period)

(Same as for A)

Refuse Sample
Group C
(third sample period)

(Same as for A)

Figure 10.17
QUEBEC INCINERATOR
Multi – sampling of Refuse – PT – 14

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TABLE 10.25
REFUSE ULTIMATE & PROXIMATE ANALISIS
PT14 MULTI-SAMPLE
LAB ANALYSIS

SUBSAMPLE :	SAMPLE "A"				SAMPLE "B"				SAMPLE "C"				OVERALL AVERAGE	STANDARD DEVIATION
	SUB 1	SUB 2	SUB 3	AVERAGE	SUB 1	SUB 2	SUB 3	AVERAGE	SUB 1	SUB 2	SUB 3	AVERAGE		
CALORIFIC VALUE	7317	7506	6939	7488	6336	6372	7686	6804	6570	6444	7497	6585	6962	515.8
MOISTURE	3.1	3.1	2.7	4.1	5.4	4.4	2.9	3.9	3.2	2.9	3.4	3.3	3.5	0.8
VOLATILE MATTER	68.6	76.3	64.8	69.6	76.4	65.3	69.0	76.5	76.7	65.7	69.1	65.3	70.3	4.7
FIXED CARBON	2.3	1.6	0.0	7.5	8.7	10.9	7.6	6.2	8.3	10.4	5.8	6.5	6.2	3.8
ASH	29.1	22.1	36.9	22.9	14.9	23.8	23.4	17.3	15.0	23.9	25.1	28.2	23.6	6.3
Cl	0.4	0.5	0.6	1.9	1.7	1.7	1.9	1.2	1.5	1.9	1.4	1.4	1.3	0.6
C	42.4	44.9	37.6	42.9	42.2	40.0	43.7	43.8	44.2	42.8	43.0	40.1	42.3	2.1
H	5.9	6.4	5.7	6.2	5.6	5.7	6.3	6.1	6.3	6.2	6.1	5.9	6.0	0.3
N	0.2	0.9	0.0	0.9	0.5	1.2	0.8	0.6	0.3	1.3	0.7	0.8	0.7	0.4
S	0.5	0.4	0.3	0.5	0.4	0.3	0.5	0.4	0.4	0.3	0.5	0.3	0.4	0.1
ASH	29.1	22.1	36.9	22.9	14.9	23.8	23.4	17.3	15.0	23.9	25.1	28.2	23.6	6.3
MOISTURE	3.1	3.1	2.7	4.1	5.4	4.4	2.9	3.9	3.2	2.9	3.4	3.3	3.5	0.8
O2 (BY DIFFERENCE)	18.3	21.7	16.2	20.7	29.3	22.8	20.6	26.7	29.1	20.7	19.9	19.9	22.2	4.2

TABLE 10.26

NITEP - QUEBEC

REFUSE FEED SUBSAMPLES FOR TEST PT14

ORGANICS ng/g

| | SAMPLE "A" | | | | SAMPLE "B" | | | | SAMPLE "C" | | | | OVERALL | |
SUBSAMPLE # :	SUB1	SUB2	SUB3	AVERAGE	SUB1	SUB2	SUB3	AVERAGE	SUB1	SUB2	SUB3	AVERAGE	SAMPLE AVERAGE	STANDARD DEVIATION
TOTAL PCDD	17	28	21	22	147	245	188	193	7	9	11	9	75	87
TOTAL PCDF	0.04	0.04	0.04	0.04	9.38	10.71	9.99	10.03	0.04	0.10	0.05	0.06	3.38	4.71
TOTAL CB	29	22	27	26	87	111	96	98	108	75	92	92	72	34
TOTAL PCB	141	93	45	93	100	84	62	82	26	8	14	16	64	42
TOTAL CP	1097	911	1033	1014	5670	6704	4880	5751	436	334	538	436	2400	2421
TOTAL PAH	3942	4000	3525	3822	9686	10337	6551	8858	2883	3036	3227	3049	5243	2751

TABLE 10.27

NITEP - QUEBEC

REFUSE FEED SUBSAMPLES FOR TEST PT-14

METALS ug/g

	SAMPLE "A"					SAMPLE "B"					SAMPLE "C"					OVERALL	
SUBSAMPLE # :	SUB1	SUB2	SUB3	SUB4	AVERAGE	SUB1	SUB2	SUB3	SUB4	AVERAGE	SUB1	SUB2	SUB3	SUB4	AVERAGE	SAMPLE AVERAGE	STANDARD DEVIATION
ANTIMONY	4.2	5.0	4.9	4.2	4.6	56.0	70.0	19.0	54.0	49.8	10.0	8.4	11.0	11.0	10.1	21.5	22.9
ARSENIC	2.1	2.5	2.6	3.6	2.7	1.9	2.4	2.0	2.1	2.1	2.7	2.5	1.8	3.1	2.5	2.4	0.5
CADMIUM	4.4	5.1	5.1	7.7	5.6	2.4	3.0	3.0	2.9	2.8	7.8	8.0	5.8	6.2	7.0	5.1	1.9
CHROMIUM	80	64	72	72	72	64	64	57	61	62	105	90	108	103	102	78	18
COPPER	60	56	81	61	65	64	54	45	166	82	657	576	642	645	630	259	265
LEAD	165	142	154	134	149	1420	1090	491	1600	1150	7100	323	287	269	1995	1098	1877
MERCURY	0.43	0.38	0.41	0.45	0.42	1.94	2.10	2.00	2.00	2.01	4.63	6.30	6.10	5.40	5.61	2.68	2.20
NICKEL	40	36	36	54	42	22	20	30	24	24	59	56	54	61	58	41	15
ZINC	168	142	157	133	150	564	849	496	477	597	1490	1500	1510	1410	1478	741	559

The multi-sampling of refuse also permitted evaluation of the refuse composition over time since the three samples were taken during different time periods of the test. The high variability in refuse composition between the samples indicated that refuse composition was not consistent over time. Consequently, these results reaffirmed the importance of obtaining large samples for analysis as well as sampling over the complete duration of the test.

10.5.3 Efficiency

Thermal efficiency is an appropriate indicator of good or poor operation of a combustion unit. To assess the operation of the Quebec Incinerator, the efficiency was calculated by the following three methods.

Combustion Efficiency

Combustion efficiency was calculated using the ratio between carbon monoxide and carbon dioxide exhaust emissions. This efficiency provided a preliminary indication of the incinerator operations through the use of the continuous gas monitoring system.

The formula used is provided below:

$$\text{Combustion Efficiency} = \left(1 - \frac{CO}{CO_2}\right) \times 100$$

Input/Output and Heat Loss Efficiency (ASME)

Input/output efficiency is based on accurate higher heating values of the refuse and ash, as well as process data.

The input/output and heat loss method as described in ASME 4.1 utilized the following inputs:

- Refuse proximate and ultimate analyses;
- Refuse and ash rates;
- Ash higher heating value;
- Steam rate, temperature and pressure; and
- Exhaust gas combustion, flow and temperature.

Bomb Calorimeter Efficiency

In the bomb calorimetric efficiency calculations, the incinerator was regarded as a bomb calorimeter to calculate the higher heating value of the refuse and subsequently the efficiency.

The refuse higher heating value (HHV) analyses from the field samples and those calculated from bomb calorimetry are presented in Table 10.28. The possibility of refuse segregation occurring during the refuse sampling was thought to have been the cause for the difference in values. This table also presents the respective efficiency calculation from ASME 4.1 "Abbreviated Efficiency Test and Bomb Calorimetry Efficiency". Volume IV presents all the appropriate details associated with these efficiency calculations.

TABLE 10.28
EFFICIENCY CALCULATION

TEST	HHV ANALYSIS BTU/lb*	ASME EFFICIENCY		BOMB CALORIMETRY	
		INPUT/OUTPUT %	HEAT LOST %	HHV BTU/lb*	EFFICIENCY %
PT-01	4929	62	60	5248	58
PT-02	3600	92	54	5320	62
PT-03	3738	77	57	4806	61
PT-04	3526	90	48	5360	60
PT-05	3853	87	62	4964	67
PT-06	3811	88	48	5568	60
PT-07	3628	105	57	5653	68
PT-09	4367	70	63	4761	64
PT-10	3865	83	52	5335	60
PT-11	3498	89	54	5041	62
PT-12	3494	89	57	4927	63
PT-13	2632	110	32	4960	59
PT-14	4359	83	60	5431	65
PT-15	3375	97	50	5302	62

* refuse as fired

The ASME efficiency was discarded due to the unrealistic values of the input/output results in comparison to the heat loss values, since this procedure relies heavily on the ultimate, proximate and HHV of the refuse.

Bomb calorimetry was eventually chosen as the appropriate efficiency calculation because this method was not affected by the refuse analysis which, as mentioned previously in Section 10.5.2, varied considerably over the test period. Secondly, most of the data used in this calculation was measured by two different means and cross-checked.

10.5.4 Boiler Inlet Temperature Stratification

As described in Sections 4.2 and 5.3, a thermocouple grid was installed at the boiler inlet for the Performance Tests. The radiation chamber grid for the Characterization Tests deteriorated rapidly due to flame impingement, erosion, and corrosion.

The radiation chamber thermocouple grid was removed after the Characterization Tests and was not replaced for the Performance Tests. This decision was based on the high replacement cost and the short time frame available between test programs.

As discussed in Section 9.4, the boiler inlet temperature stratification showed a similar trend during the Performance Tests as in the Characterization Tests. Figures 10.18 and 10.19 present the temperature gradients for PT-01 and PT-02.

As suspected, lower temperatures were measured in the higher section of the boiler inlet. This phenomenon can be explained by the fact that the retention time for the upper flue gases in the radiation chamber was longer as compared to that of the lower flue gases at the boiler inlet. Retention time is subsequently discussed in Section 10.5.5.

The lower boiler inlet temperatures showed an uneven temperature distribution. Temperature differences of 100 C degrees were measured between the east side (higher) as compared to the west side (lower) of the radiation chamber. It was assumed that temperature variation was due to an uneven distribution of the secondary air.

10.5.5 Retention Time

One of the most important aspects of incinerator design is the combustion gas retention time within the combustion zone. The refuse burning zone, radiation chamber, and boiler section volumes of the test unit were 138.5 m^3, 182.1 m^3, and 280.6 m^3, respectively.

The retention time in the burning zone, as presented in Table 10.29, varied from 1.6 to 2.0 sec., from 2.4 to 3.0 sec. for the radiation chamber, and from 6.5 to 8.0 for the boiler section. The retention times were calculated using the average exhaust flue gas rate and temperature. The combustion gas rate at different points in the process was back-calculated using the boiler outlet, middle inlet, and upper and lower radiation chamber temperatures.

Figure 10.18

Boiler Inlet Temperature Distribution - PT-01
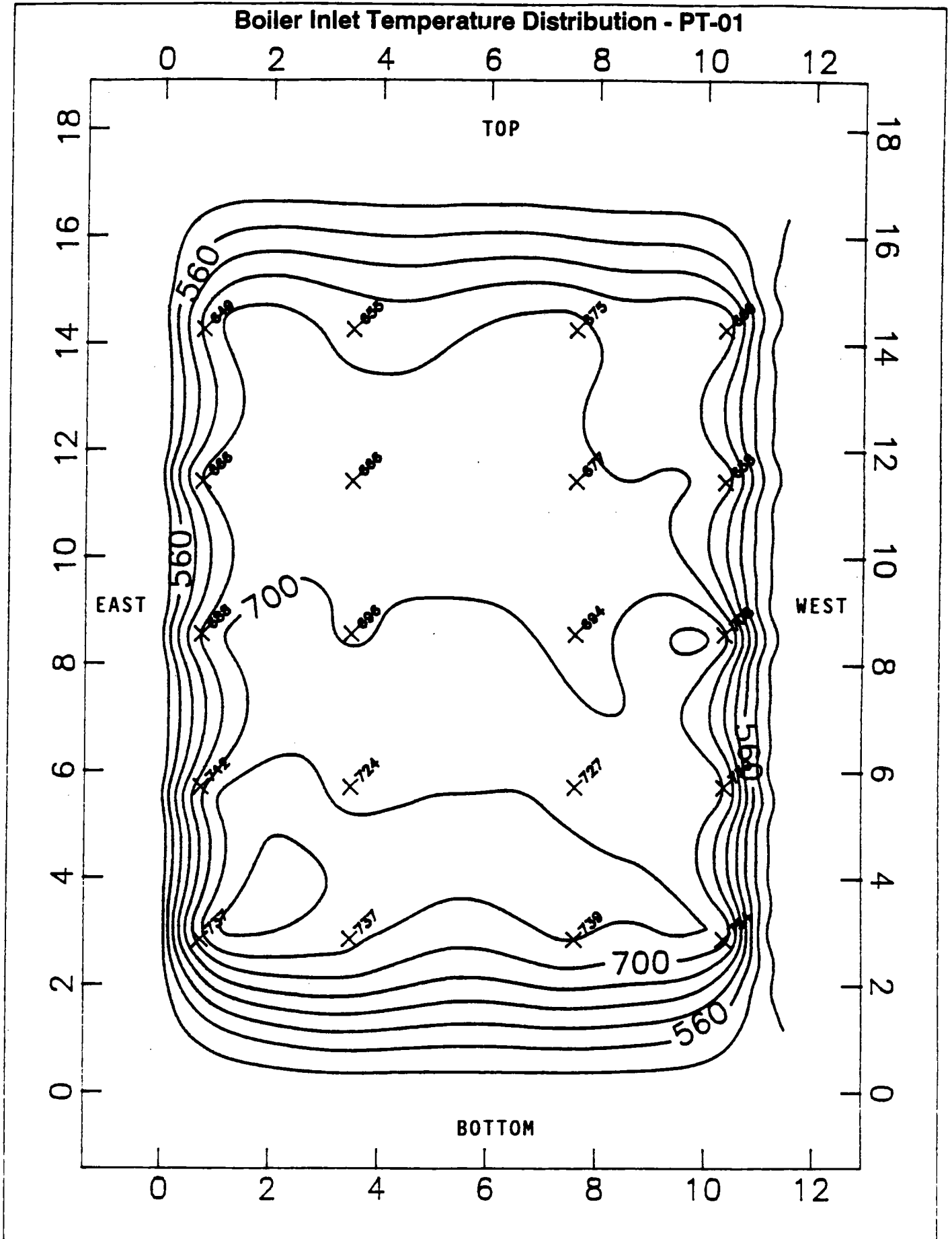
Figure 10.19
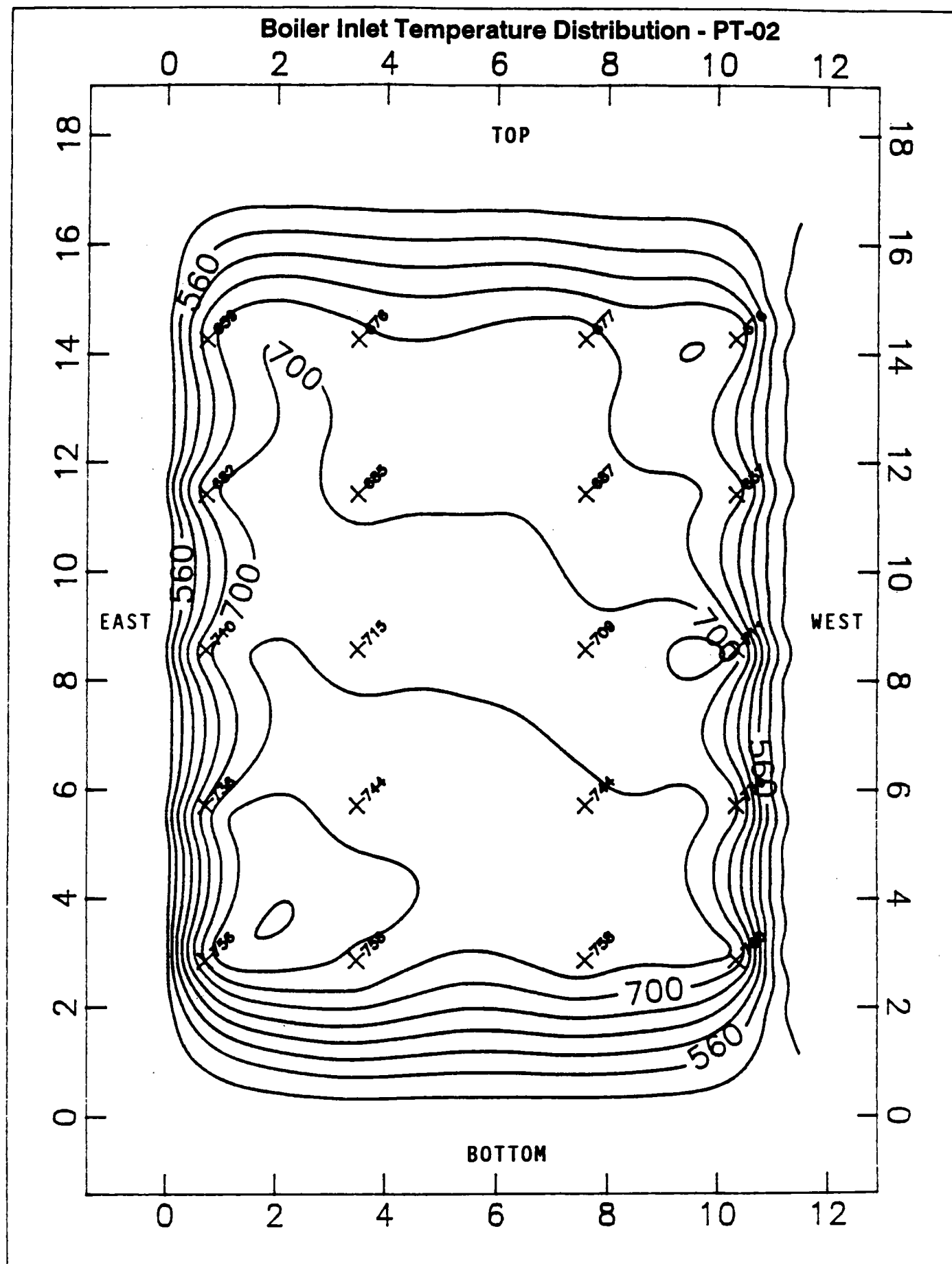
Table 10.29
PROCESS GAS RESIDENCE TIME (sec)

Performance Test	Refuse Burning Zone	Radiation Chamber	Boiler Section
PT-01	2.0	3.0	8.0
PT-02	2.0	2.9	7.7
PT-03	2.0	2.8	7.4
PT-04	2.0	2.9	7.6
PT-05	1.7	2.4	6.7
PT-06	1.6	2.4	6.7
PT-07	1.6	2.4	6.5
PT-09	1.7	2.4	6.7
PT-10	2.0	2.8	7.5
PT-11	2.0	2.8	7.4
PT-12	1.7	2.5	6.7
PT-13	1.7	2.5	6.7
PT-14	1.8	2.6	7.2
PT-15	1.8	2.6	7.2

10.5.6   Precipitator Efficiency

The removal efficiency of the electrostatic precipitator, as presented in Table 10.30, was as high as 98% (on average) for the non-volatile inorganic compounds. As expected, a poor efficiency for mercury was revealed, i.e., 11%.

10.5.7   Total Organics and Metals Content in the Ash

Total Organics

Concentrations of trace organics in the incinerator ash were fairly consistent between the five operating modes, with the exception of CB and PAH, as shown in Table 10.31. CB and PAH did not seem to follow any specific trends with respect to the mode of operation.

Boiler ash trace organic levels for four of the five operating modes were similar. For the fifth operating mode (i.e. good operating condition at low burning rate) the boiler ash trace organic concentration was up to 5 times the average of the other 4 operating modes.

Trace organic levels in the precipitator ash were fairly consistent between the operating modes, with the maximum levels occurring during the poor air distribution, poor operating condition.

TABLE 10.30
NITEP - QUEBEC
PRECIPITATOR
REMOVAL EFFICIENCY

	PT-02	PT-03	PT-04	PT-05	PT-06	PT-07	PT-09	PT-10	PT-11	PT-12	PT-13	PT-14	PT-15	AVERAGE
Particulate Removal Efficiency	98%	98%	99%	98%	98%	97%	98%	98%	98%	98%	98%	97%	98%	98%
Organics Removal Efficiency														
- PCDD	93%	87%	83%	98%	98%	95%	95%	97%	97%	97%	90%	93%	90%	93%
- PCDF	68%	70%	68%	79%	86%	79%	81%	81%	68%	87%	80%	69%	68%	76%
- CB	20%	24%	31%	16%	24%	41%	35%	37%	29%	37%	39%	30%	29%	30%
- PCB	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	7%	1%
- CP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
- PAH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Metals Removal Efficiency														
- Sb	97%	95%	93%	98%	97%	95%	95%	96%	92%	95%	94%	89%	92%	94%
- Cd	98%	94%	95%	99%	98%	96%	97%	98%	97%	97%	96%	93%	96%	96%
- Cr	98%	98%	99%	99%	99%	98%	98%	98%	98%	98%	98%	98%	99%	98%
- Pb	98%	91%	96%	98%	98%	95%	93%	96%	97%	95%	95%	90%	95%	95%
- Hg	7%	12%	8%	10%	11%	10%	13%	9%	7%	13%	10%	14%	16%	11%
- Ni	92%	96%	98%	95%	97%	98%	94%	95%	95%	96%	96%	98%	98%	96%
- Zn	99%	94%	96%	99%	99%	96%	98%	97%	97%	98%	96%	94%	97%	97%
- Cu	98%	96%	97%	99%	98%	97%	98%	98%	98%	97%	97%	96%	97%	97%
- As	99%	97%	96%	99%	99%	95%	99%	99%	99%	97%	98%	94%	96%	98%

TABLE 10.31
NITEP - QUEBEC
TOTAL ORGANICS
ASH SUMMARY
TEST GROUP AVERAGE VALUES

	INCINERATOR ASH ng/g					BOILER ASH ng/g					PRECIPITATOR ASH ng/g				
FEED RATE :	LOW	DESIGN	HIGH	DESIGN	DESIGN	LOW	DESIGN	HIGH	DESIGN	DESIGN	LOW	DESIGN	HIGH	DESIGN	DESIGN
TEMPERATURE :	LOW	DESIGN	DESIGN	LOW	LOW	LOW	DESIGN	DESIGN	LOW	LOW	LOW	DESIGN	DESIGN	LOW	LOW
CONDITION :	GOOD	GOOD	GOOD	POOR	POOR	GOOD	GOOD	GOOD	POOR	POOR	GOOD	GOOD	GOOD	POOR	POOR
PT's	2-10-11	5-6-12	7-9	3-4	14-15	2-10-11	5-6-12	7-9	3-4	14-15	2-10-11	5-6-12	7-9	3-4	14-15
TOTAL PCDD	0.11	0.21	-	0.16	-	135	37	23	43	51	757	584	620	605	945
TOTAL PCDF	0.12	1.01	-	-	-	122	31	26	25	17	219	186	257	233	260
TOTAL CB	16	45	4	5	4	1567	356	531	311	259	963	892	1663	1381	1515
TOTAL PCB	-	-	-	-	-	-	-	-	-	-	5	-	-	12	24
TOTAL CP	10	16	20	-	11	112	80	102	68	59	1242	1820	1701	1287	2968
TOTAL PAH	153	538	498	155	320	71	25	21	33	69	101	111	103	122	331

" - " = non-detectable

The consistency between operating modes indicated that there was no relationship between trace organic concentrations in the ash and good or poor operation.

The concentration distribution between the different ashes showed that precipitator ash concentrations were consistently greater than boiler ash concentrations which in turn were greater than the incinerator ash concentrations.

Metals

Material collected from the three ash locations were analyzed for metals. Thirty metals were investigated for the Quebec program; Table 10.32 reports the metals concentrations in the ashes for nine of the most important metals. Upon review of the metals concentrations, it appears that for the most part the concentrations were of the same magnitude between the operating modes, yet highly variable between ash type, as expected. These results indicate as discussed for the trace organics, that the operating mode did not directly affect the metals concentrations in the ash.

As seen in Table 10.32, six metals (Sb, As, Cd, Pb, Hg, Zn) followed the same pattern as observed for the organics concentrations in the different type of ashes. The precipitator ash showed the highest concentration and the incinerator ash the lowest concentration. However, a similar pattern was not shown for chromium, copper and nickel.

10.5.8   Hydrochloric Acid Emission Comparison

Hydrochloric acid was measured by the continuous gas monitoring system and by the wet method using a standard isokinetic train as described in Section 5.5.6.

Table 10.33 and Figure 10.20 present the hydrochloric acid emissions for the two sampling methods. On comparison of the two methods, the results showed a fairly good correlation between the two methods.

Averages of the values measured by the continuous gas monitor were recalculated over the identical time period over which the manual sampling train was run for comparison purposes.

10.6   PLASTIC CLASSIFICATION

To obtain a better understanding of the amount and types of plastics found in the incoming refuse at the Quebec Incinerator, a plastic classification program was performed during the Performance series of tests. Section 5.2.4 of this volume outlines the methodologies used.

TABLE 10.32
NITEP - QUEBEC
METALS
ASH SUMMARY
TEST GROUP AVERAGE VALUES

	INCINERATOR ASH ug/g					BOILER ASH ug/g					PRECIPITATOR ASH ug/g				
FEED RATE :	LOW	DESIGN	HIGH	DESIGN	DESIGN	LOW	DESIGN	HIGH	DESIGN	DESIGN	LOW	DESIGN	HIGH	DESIGN	DESIGN
TEMPERATURE :	LOW	DESIGN	DESIGN	LOW	LOW	LOW	DESIGN	DESIGN	LOW	LOW	LOW	DESIGN	DESIGN	LOW	LOW
CONDITION :	GOOD	GOOD	GOOD	POOR	POOR	GOOD	GOOD	GOOD	POOR	POOR	GOOD	GOOD	GOOD	POOR	POOR
PT's	2-10-11	5-6-12	7-9	3-4	14-15	2-10-11	5-6-12	7-9	3-4	14-15	2-10-11	5-6-12	7-9	3-4	14-15
ANTIMONY	12	16	9	26	10	342	332	270	96	265	553	753	525	730	328
ARSENIC	7.7	6.8	8.3	5.7	7.7	83	91	74	45	54	133	170	130	67	46
CADMIUM	3.4	3.8	2.8	3.6	4.2	286	206	153	135	211	877	1062	764	514	475
CHROMIUM	230	250	363	231	171	331	304	338	318	235	454	479	516	527	348
COPPER	1773	2543	4509	2245	1308	636	530	480	541	528	1323	1483	1295	946	926
LEAD	766	1757	867	1323	1638	9323	7478	6635	5511	8655	20667	21133	17150	10750	11800
MERCURY	0.0027	0.0311	0.0418	0.0087	0.0038	8.3	6.8	5.9	3.6	2.9	49	72	73	32	41
NICKEL	102	131	428	89	72	111	115	101	113	109	100	108	118	98	108
ZINC	2307	1783	1531	2551	1172	17600	17400	15650	11100	12750	60900	60700	44750	33800	27300

Figure 10.20 : EMISSION COMPARISON FOR HYDROCHLORIC ACID
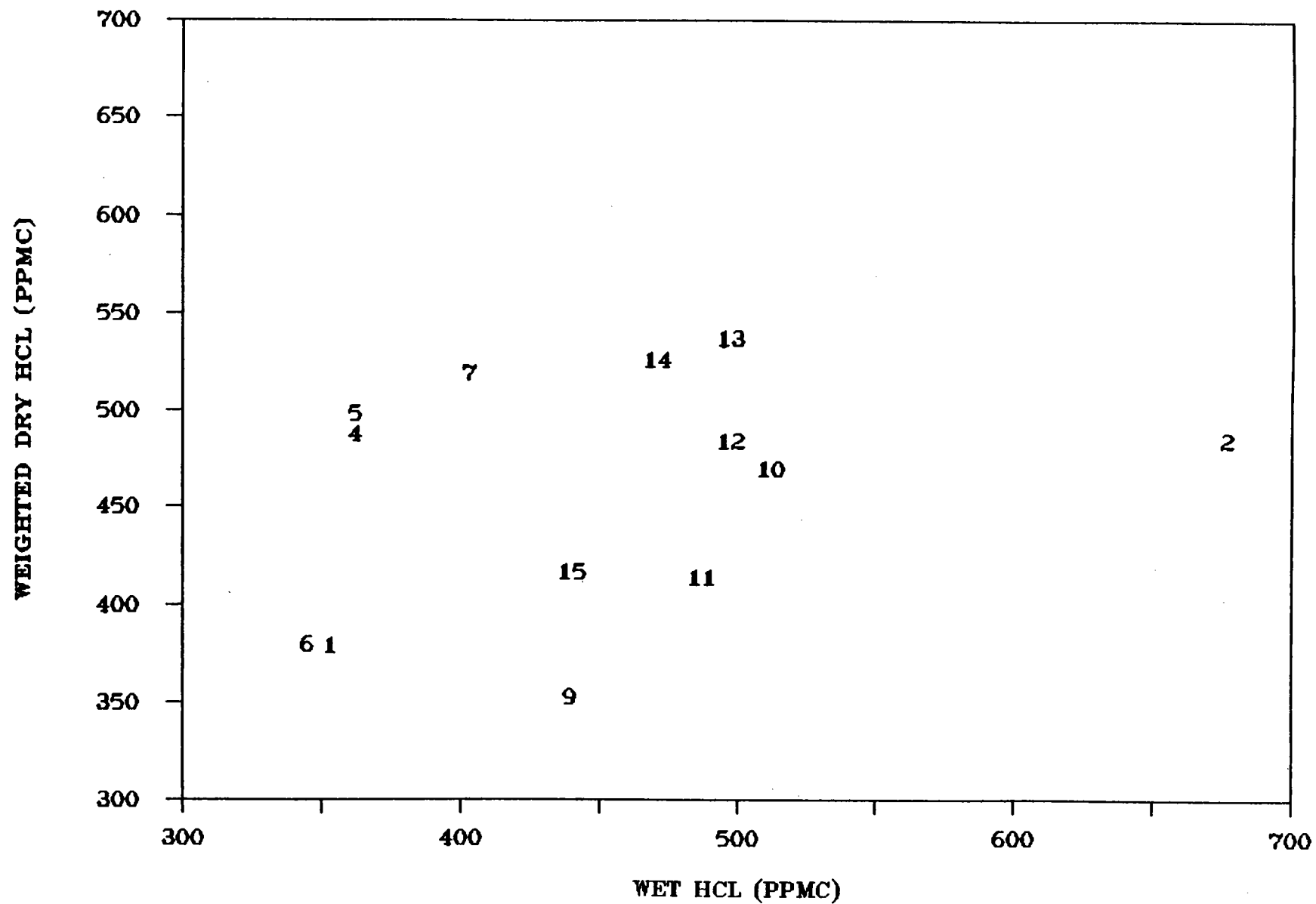
Table 10.33
HYDROCHLORIC ACID EMISSIONS

Performance Test	SAMPLING TRAIN [HCl] ppm	EXHAUST GAS CONTINUOUS MONITORING	
		OVERALL AVE. [HCL] ppm	CORRESPONDING TIME PERIOD AVERAGE [HCl] ppm
PT-01	353	384	379
PT-02	677	565	485
PT-03	664	N/A	N/A
PT-04	362	453	488
PT-05	362	504	498
PT-06	345	366	380
PT-07	403	512	519
PT-09	439	369	353
PT-10	512	465	470
PT-11	487	466	414
PT-12	497	487	484
PT-13	497	500	537
PT-14	471	594	526
PT-15	440	447	417

Since the classification procedure took approximately 2 days to perform per sample taken, only 8 assessments were carried out during the Performance Tests.

Based on the program findings, the plastic concentration in the refuse varied from 5.6% up to 10.1% with an average of 7.9%, as shown in Table 10.34. Plastic films, consisting mainly of garbage bags, represented 53.9%, rigid or molded plastics 41.5%, and foam 4.6% by weight of the total plastics (Table 10.35).

TABLE 10.34
PLASTIC CONCENTRATION IN THE REFUSE

PT	REFUSE WEIGHT kg	PLASTIC CONCENTRATION %
1	616	8.8
3	1283	6.5
5	753	9.2
7	969	8.4
9	88	8.6
11	797	5.6
13	392	10.1
14	469	5.9
AVERAGE	746	7.9

TABLE 10.35
PLASTIC CONCENTRATION by PRODUCT TYPE
(% of Total Plastic in Feed)

No.	Performance Test	Plastic Bags	Film	Plastic Molds	Foam	Composite Material
1	1	13.6	38.0	44.8	3.7	--
2	3	12.0	39.3	43.1	5.6	--
3	5	11.9	36.6	48.1	3.3	--
4	7	10.5	44.9	38.8	5.8	--
5	9	11.8	42.4	40.2	5.4	0.3
6	11	12.1	45.1	36.6	6.2	--
7	13	8.1	61.6	29.5	0.8	--
8	14	11.5	35.6	48.9	4.0	--
AVERAGE :		11.5	42.4	41.5	4.6	--

When considering plastic types, polyethylene terephthalate (PET) was considered separately to emphasize the importance of plastic bottles (i.e. PET is mostly used in plastic bottles for soft drinks) (Table 10.36).

TABLE 10.36
PLASTIC CONCENTRATION by PLASTIC TYPE
(% of Total Plastic in Feed)

No.	Performance Test	Poly-olefins	Poly-styrene	PVC	PET	Others
1	1	51.4	33.9	9.2	0.2	5.5
2	3	63.7	29.8	3.0	--	3.5
3	5	72.3	22.0	1.9	0.3	3.6
4	7	54.4	20.7	0.2	0.1	4.6
5	9	52.6	43.2	3.2	--	1.0
6	11	66.5	1.0	1.3	0.2	0.9
7	13	93.2	2.8	2.0	--	2.0
8	14	59.0	32.0	2.5	0.4	6.1
AVERAGE :		63.0	27.2	6.3	--	3.5

The low level of PET in the Quebec City refuse was not surprising due to the fact that all soft drinks and beer containers (glass, plastic, steel, aluminum, etc.) have a relatively high refundable value. Furthermore, in Quebec, 77% by volume of all soft drinks sold are in returnable glass bottles.

Acrylonitrile-Butadiene-Styrene (ABS), nylon and those plastics which were not physically possible to separate (rare occasions), were classified as "Others".

The polyolefins, polyethylene (PE) and polypropylene (PP), represented the largest category of plastics in the refuse, 63.0% of the total weight, as shown in Table 10.36. These compounds are most widely used in garbage bags and packing because of their low costs and valuable properties.

Polystyrene was second in importance, representing 27.2% of the total plastic composition. It was estimated that in Quebec, 80% of the polystyrene is found in rigid containers.

Polyvinyl chloride (PVC) is used mostly in transparent rigid containers, but because of its high cost is not widely used. Consequently, only 6.3% of the plastic component contained PVC.

A comparison of these results with similar studies in Japan and France, as presented in Table 10.37, indicates that the polyethylene, polypropylene and polystyrene levels are of a similar order of magnitude. However, the PVC level is lower by a factor of 2 to 3. In France the high level of PVC can be attributed to the high consumption of bottled water in PVC containers, whereas in Canada, only 9% of the plastic bottles are fabricated with PVC. In Canada PVC is mostly used to fabricate durable goods such as window frames and hoses.

TABLE 10.37
PERCENTAGE OF DIFFERENT PLASTIC TYPES IN MUNICIPAL REFUSE FOR CUQ, JAPAN, AND FRANCE

Plastic Type		France	Japan (1980-82)	C.U.Q. (1986)
Polyolefins:	TOTAL	57	57	63
	(PE)	50		
	(PP)	7		
Polystyrene:	TOTAL	19	25	27
	(PS)	16		
	(EPS)	3		
PVC:	TOTAL	21	15	6
Others		3	3	4

11.0 PROCESS AND EMISSION CORRELATIONS

Chapter 10.0 summarized the results of the Performance Test Program. The data analysis primarily consisted of comparisons between averaged results of individual and replicate test run averages.

This chapter summarizes the statistical analysis performed using the individual test data. The primary goals of this statistical analysis were to identify:

- how various incinerator operating parameters affected emissions, and

- whether certain emissions or operating parameters can be utilized as surrogate indicators for predicting trace organic emission concentrations.

The results presented in this section summarize the statistical analysis carried out on a total of 148 parameters. All parameters were analyzed using correlations to determine the most significant findings. Combining the trace organics data with the findings of the correlations, simple and multiple linear regression analyses were carried out to determine if any trends and/or correlations existed. These correlations were subjected to several levels of screening which determined their significance for further discussion in this section.

The statistical analyses consisted of the following correlations:

- simple linear regression of selected organic and inorganic emissions vs. continuous gas data and process operating variables in order to identify the most important parameters for multiple linear regression; and

- multiple linear regression of selected organic emissions vs. continuous gas data and process operating variables, in order to develop a model which would enable predicting and/or controlling organic emissions.

The type of statistical analysis presented in this section pertains to correlations and determination coefficients. The data base employed only the individual test run averages. All determination coefficients between emissions and process parameters and the summary data used for the determination of the coefficients, are presented in Volume IV.

The following are discussed in this Chapter:

- statistical analysis methodology (11.1);
- data analysis strategy (11.2);
- simple linear regression analysis results (11.3); and
- multiple linear regression analysis results (11.4).

11.1 STATISTICAL ANALYSIS METHODOLOGY

The statistical analysis technique used to identify correlation relationships in this section, was regression analysis. This technique generates a mathematical model that best describes the relationship between sets of data. Regression models are used for describing data, estimating unknown values, and most importantly, for predicting and estimating emissions from other variables. Appendix D provides a more completed description.

The Significance of the r^2 Value

In most research it is difficult to find a regression line, especially a straight one, which perfectly fits the data. A measure of the "goodness of fit" is given by 'r' and 'r^2'.

As defined above, r^2 essentially is a measure of total variance explained by a linear correlation between two variables. Values of r^2 can be judged on a relative basis (comparing parameter to parameter) or on an absolute basis (defining a minimum value of r^2 for a correlation to be judged acceptable). Colton (1974) suggests that values of r^2 for different levels of fit can range from 0.13 to 0.56. Larger values of r^2 than those suggested by Colton to describe the same range of relationships (poor, good, excellent) are probably appropriate for this study and suggested by NRC (1984). Table 11.1 provides the information for experimental correlation data. Each of these references assume that a sufficiently large number of data points are used to provide the r^2 values. Large sample sizes effectively lower the level at which a correlation between two variables becomes significant.

TABLE 11.1
SIGNIFICANCE OF EXPERIMENTAL CORRELATION DATA

Correlation	r^2 Colton (1974)	r^2 Controlled Experiment	r^2 Field Study
Little or No	0.13	-	-
Fair	0.25	0.50	0.45
Moderate	0.56	0.65	0.55
Good	>0.56	0.80	0.65
Very Good	-	0.90	0.80
Excellent	-	0.95	0.90

For this test program, 13 pairs of data were selected for simple linear regression analysis based on 13 test runs. From a standard statistical correlation table, the critical r^2 value for 13 pairs of data for a 5% significance is 0.306. The use of the critical value at the 5% significance level allows one to determine if correlations exist between variables. Therefore, for 13 pairs of data (5% significance) in this case, if the calculated r^2 value is less than 0.306, no correlation exists between the compared variables. Once establishing if a correlation does exist for any r^2 value, Table 11.1 allows one to assess the relative strength of the fit between different parameters.

For the simple and multiple linear regression models, the calculation of the r^2 value was based upon standard statistical practice involving the calculation of both the standard deviations of the various data sets and the co-variance between the data sets.

11.2 STRATEGY USED IN APPROACH TO DATA ANALYSIS

11.2.1 Dependent and Independent Variables

One of the primary objectives of this study was to assess the influence of different operating conditions on emissions, focussing on trace organics, particulates and heavy metals. The emissions of particular interest in this project are:

- dioxins (PCDD),
- furans (PCDF),
- chlorophenols (CP),
- chlorobenzenes (CB),
- polycyclic aromatic hydrocarbons (PAH),
- polychlorinated biphenols (PCB),
- particulates, and
- heavy metals.

The above emissions were designated as the **dependent variables** for simple linear regression analysis.

Independent variables were selected keeping the following two objectives in mind, namely:

a) **Prediction Models** - to establish a method of predicting the amounts of these pollutants from more readily measurable parameters (surrogates), and

b) **Control Models** - to identify operating conditions or limits that when adhered to, would control the concentrations of pollutants leaving the incinerator.

To attain these objectives, the independent variables were separated into two groups. Those that were used to generate the **Prediction Models** are referred to as the "monitoring variables". Those that were used to generate the **Control Models** are referred to as the "operating variables".

These **independent variables** are grouped and identified as follows:

The monitoring variables are:

(i)   lower radiation chamber temperature ($^{\circ}$C),

(ii)   upper radiation chamber temperature ($^{\circ}$C),

(iii)   excess air expressed by excess oxygen (%),

(iv)   flue gas moisture (%),

(v)   CO concentration in the flue gas (ppm), and

(vi) NO_x concentration in the flue gas (ppm).

Some of the operational variables or settings that could be controlled on the tested incinerator are:

(i)   primary air (i.e. underfire air) (Sm^3/min),

(ii)   secondary air (i.e. overfire air) (Sm^3/min),

(iii)   total air (Sm^3/min),

(iv)   primary/secondary air ratio,

(v)   secondary front/rear ratio, and

(vi)   throughput expressed as steam rate (tonne/h).

All simple linear regression graphs presented in this chapter show two straight line relationships. The line labelled 'Good' represents the results of the statistical analysis containing only the "good" operating conditions (i.e. excluding PT-01, PT-03, PT-04, PT-13, PT-14, and PT-15). The line labelled 'All' represents the results of the statistical analysis with all the Performance Tests, except PT-01 (preliminary test).

11.2.2   Other Variables Considered

The following relationships between selected monitoring and operating variables were also examined:

- dioxin vs. selected parameters (e.g. dioxin vs. copper);
- furans vs. selected parameters;
- particulate emissions vs. selected parameters;
- metals emission vs. selected parameters;
- process temperatures vs selected parameters;
- process air flow vs. selected parameters;
- continuous gas emission vs. selected parameters; and

- trace organics emission vs. metals concentration in the ash.

11.3 CORRELATIONS AND SIMPLE LINEAR REGRESSION ANALYSIS

Correlation results between the dependent variables (i.e. trace organics, particulate and heavy metal emissions) versus one of the aforementioned independent variables (monitoring, operating and other) are presented in this section.

The determination coefficients for the best-fit models of the above mentioned emissions are also presented in this section.

11.3.1 Dioxin Correlations

Dioxin is viewed by the scientific community as the major trace organic compound to be controlled in the combustion process of a municipal waste incinerator. As demonstrated in this chapter and subsequently in section 11.4.2, significant relationships were found to exist between dioxin versus monitoring, operating and other variables.

It is generally accepted that the destruction of trace organic components by incineration is a function of "the three T's of combustion" i.e. residence Time, process Temperature and satisfactory Turbulence in the incinerator (ref. U.S. Toxic Substances Control Act (TSCA) 44 FR 106 paragraph 761.40). As described in the following section, the three T's are directly controlled by operating variables.

For the purpose of this study, it was assumed the effectiveness of the electrostatic precipitator to remove trace organics was constant. This assumption was based on the relatively constant efficiency of the precipitator to remove particulates and metals, and the good correlation that existed between the particulate and dioxin emissions ($r^2 = 0.64$).

Operating Variables

The Quebec incinerator was equipped with the ability to automatically control:

a) combustion air distribution (which had a direct impact on Turbulence), and

b) primary and secondary air flows (which impacted on both Time and Turbulence).

The total combustion air, refuse feed rate, refuse quality, grate operation, and secondary air flow, determined the furnace radiation temperature. In general, the retention time varied inversely with the total air flow under similar temperature conditions.

Table 11.2 presents the correlations between dioxin concentration and the operating variables of concern. The correlations of exhaust gas and primary air flows to dioxins (Table 11.2) were significant, with r^2 values of 0.87 and 0.83, respectively. Both these parameters related to residence Time and Turbulence and influenced solids transport velocities. It is interesting to note that when the incinerator was operating under "good" operating conditions, dioxin emissions showed no correlation with the primary air flow rate. On the other hand, a strong correlation was obtained when all operating conditions were considered ($r^2 = 0.83$), as shown in Figure 11.1.

Figure 11.1

PCDF vs PRIMARY AIR
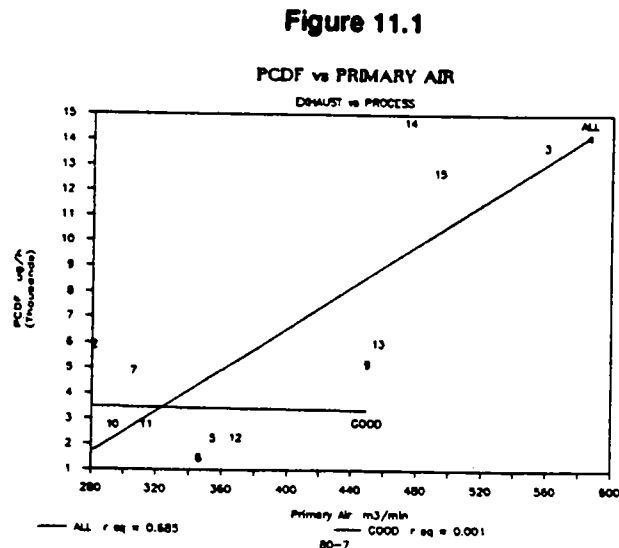
TABLE 11.2
PCDD Correlations
Operating Variables

Correlated Parameters	Determination Coefficients (r^2)
Lower Radiation Chamber Temp. ($^\circ$C)	0.19 (No correlation)
Upper Radiation Chamber Temp. ($^\circ$C)	0.20 (No)
Boiler Inlet Temp. ($^\circ$C)	0.15 (No)
Exhaust gas flow (Sm^3/min)	0.87 (Very good correlation)
Primary Air (m^3/min)	0.83 (Very good)
Secondary Air (m^3/min)	0.04 (No)

Monitoring Variables

Based on the results presented, in Table 11.3, weak correlations were observed for dioxin emissions versus lower radiation chamber, upper radiation chamber and boiler inlet temperatures. However, upon closer examination of the scatter plot in Figure 11.2, there appears to be a significant correlation of PCDD emissions versus incinerator temperature, if the test points 2, 10 and 11 (which are at the low feed rate) are considered to be part of a second family of curves. The remaining tests (which are at the design and high feed rates) provide correlations with significant r^2 values of over 0.7. Unfortunately, there were only 3 tests at the low rate; data for other temperatures at this rate are needed to conclusively determine if two separate curves do exist.

Figure 11.2 : Dioxin vs Process Temperature

PCDD vs LOWER RADIATION CHAMBER TEMP.

EXHAUST GAS vs PROCESS

ALL r sq = 0.158   GOOD r sq = 0.120

36-9

PCDD vs BOILER INLET TEMP.

EXHAUST GAS vs PROCESS

ALL r sq = 0.147   GOOD r sq = 0.043

36-127
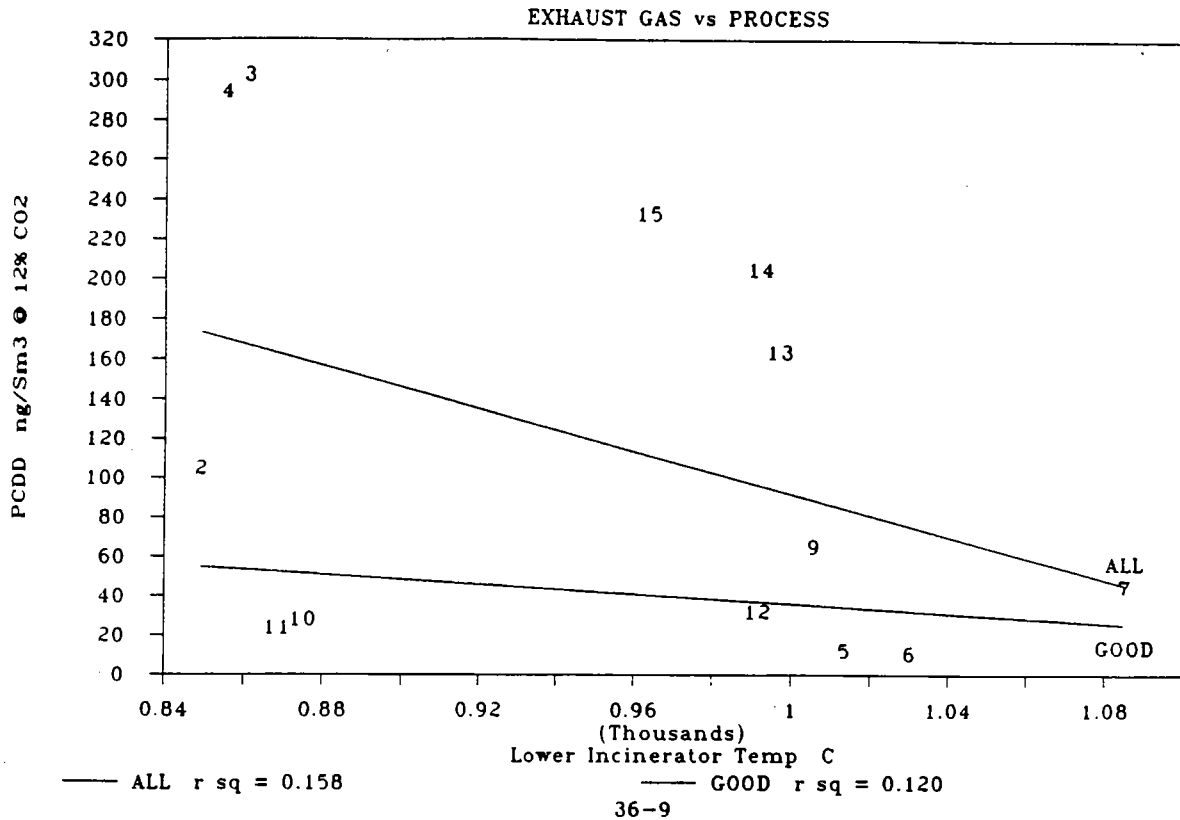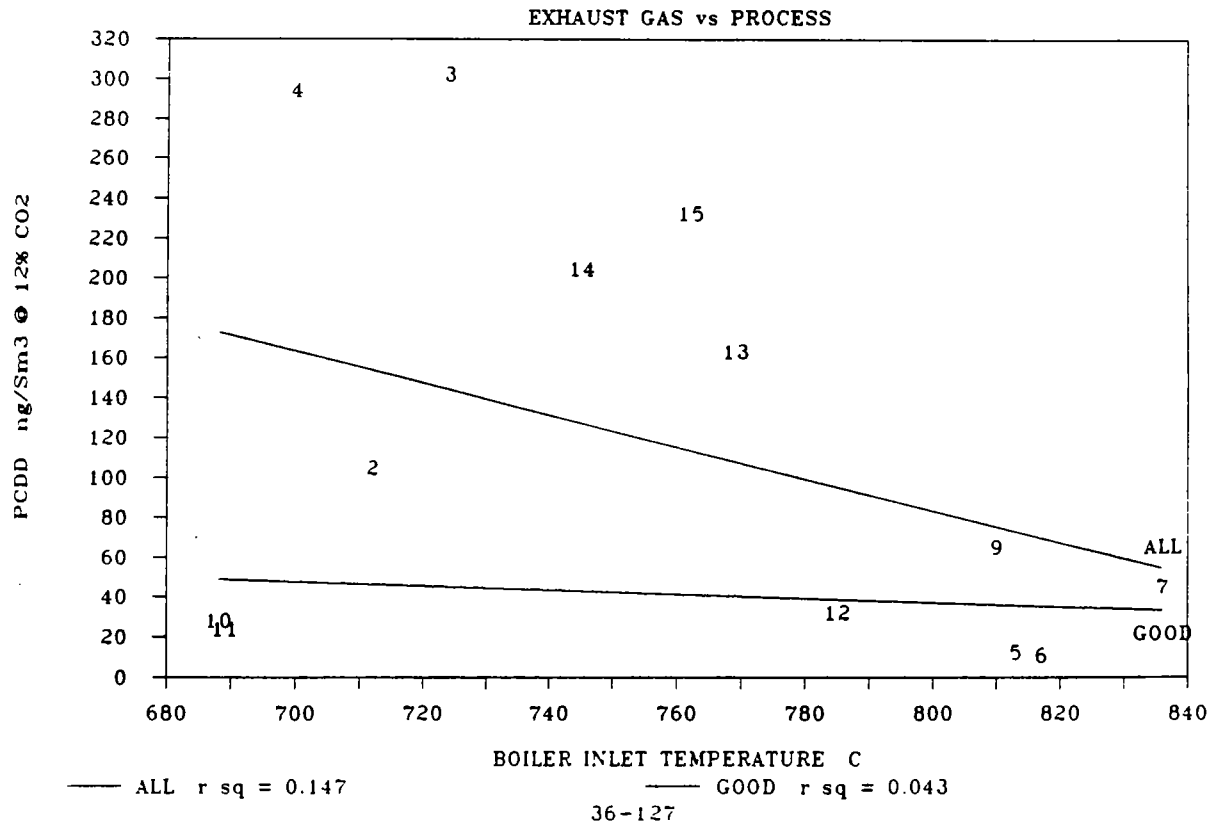
TABLE 11.3
PCDD Correlations
Monitoring Variables

Correlated Parameters	Determination Coefficients (r^2)
Particulate	0.64 (Good correlation)
Cd	0.74 (Very good)
Cu	0.77 (Very good)
Zn	0.70 (Very good)
Lower Radiation Chamber Temp. ($^\circ$C)	0.19 (No correlation)
Upper Radiation Chamber Temp. ($^\circ$C)	0.20 (No)
Boiler Inlet Temp. ($^\circ$C)	0.15 (No)
CO	0.61 (Good)
NO_x	0.38
SO_2	0.31
Excess Air	0.16
HCl	0.005 (No)

A comparison of CO and total dioxin concentration indicated a fair correlation (r^2 = 0.51) as shown in Figure 11.3. However, no correlation occurred when only good operating conditions were considered.

Table 11.3 also shows the determination coefficients calculated for dioxin versus NO_x, HCl, SO_2 and excess air (O_2) which ranged from very poor to no correlation. The variations and conditions within the good runs may have been too small to show large enough variations in the monitored parameters.

Other Variables

Based on the results presented in Table 11.3, correlations of dioxin versus emissions of particulates and specific metals (Cd, Cu and Zn) were very strong, as previously shown in Figure 11.3. Of important note, is the strong correlation between the dioxin concentrations and the copper concentrations. It has been suggested by other studies that copper may be a catalyst for the formation of dioxin. This feeling appears to be supported by this study with a resultant correlation coefficient of r^2 = 0.77. It should be noted that a significant weakening of the correlations occurs when only the good operating conditions are considered.

Dioxin concentrations in the refuse in comparison to concentrations in the precipitator ash and stack emissions, were poor with r^2 = 0.15 and r^2 = 0.09, respectively. This suggests that possible physicochemical changes were occurring in the furnace.

In Figure 11.4, correlation graphs between dioxin and other trace organic emission concentrations are presented. These graphs show that the dioxin exhaust concentration correlated very well with furan (PCDF), chlorobenzene (CB), and chlorophenol (CP) concentrations. Therefore, it appears that a

Figure 11.3 : Dioxin vs Monitoring Variables

PCDD vs COPPER

PCDF vs COPPER

PCDD vs ZINC

PCDF vs ZINC

PCDD vs CADMIUM

PCDF vs CADMIUM
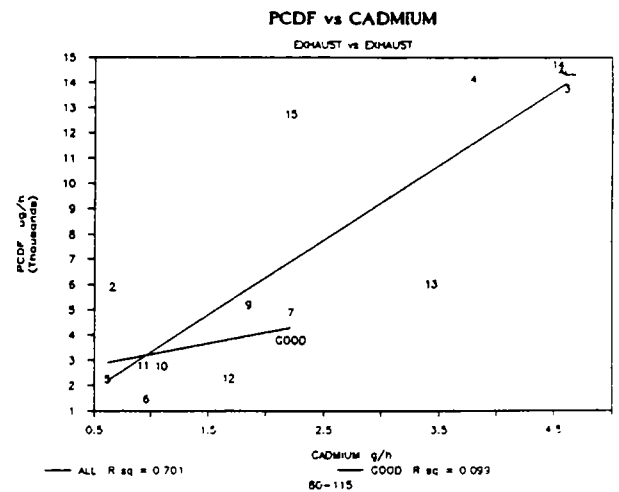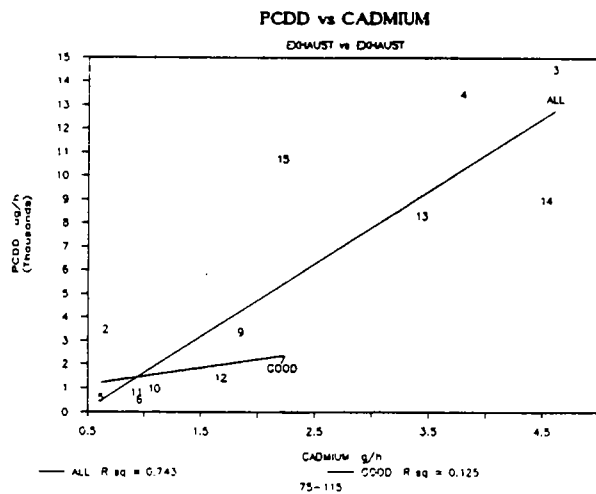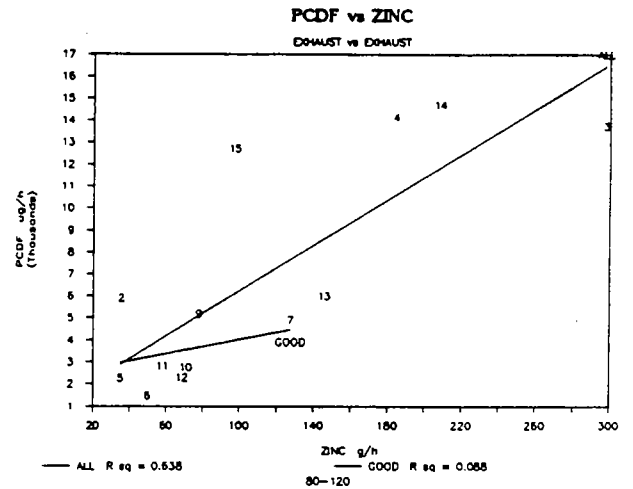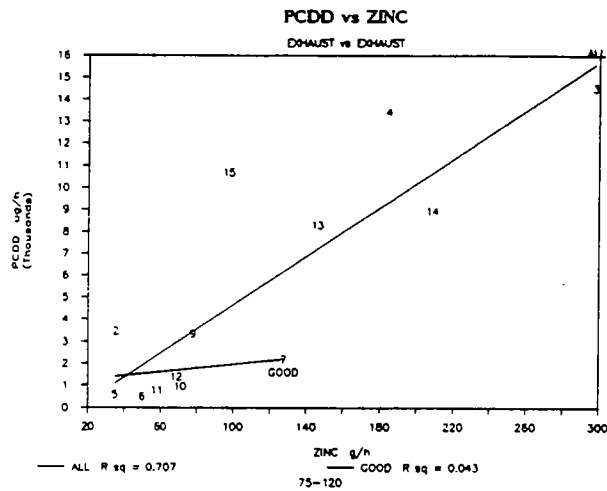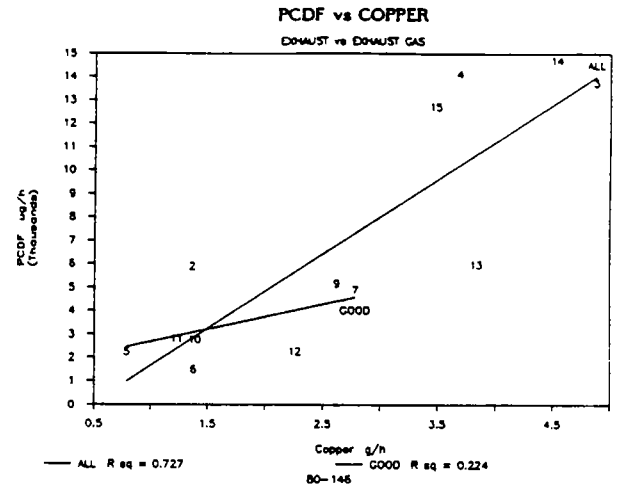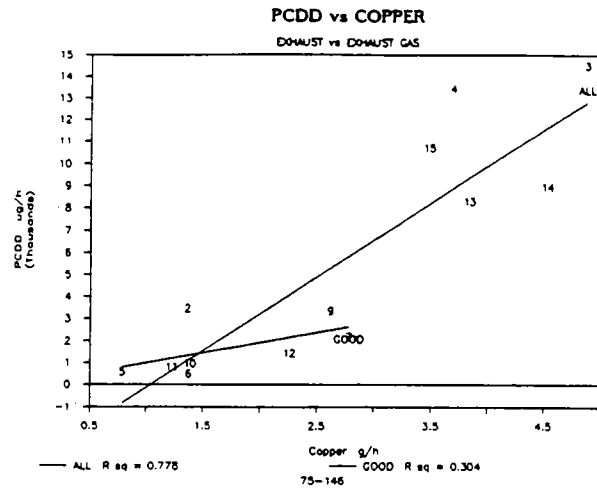
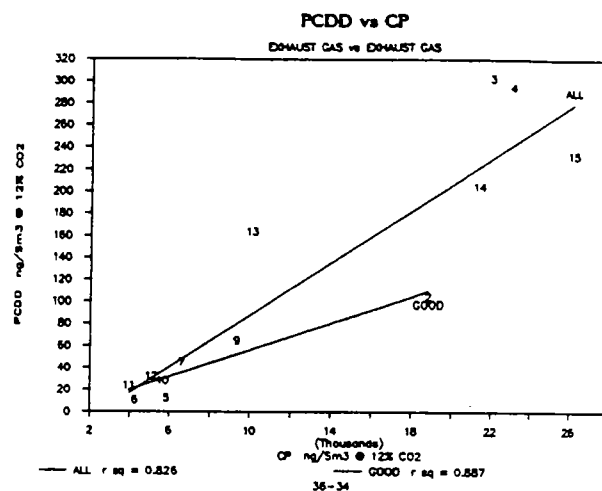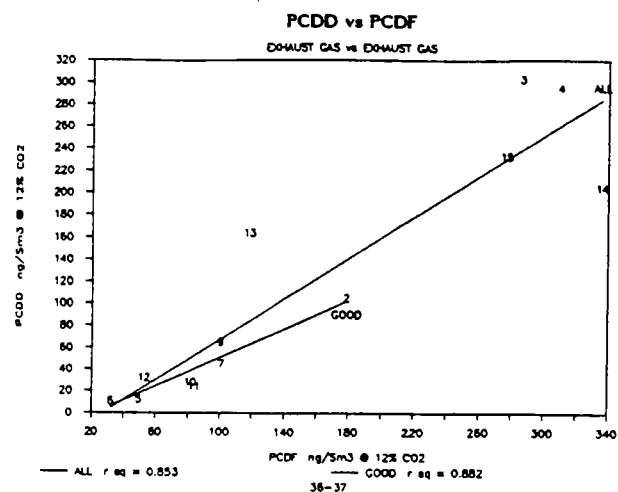# Figure 11.4 : Furan vs Trace Organics

PCDD vs PCDF

PCDD vs CP

PCDD vs PCB

PCDD vs PAH

PCDD vs CB
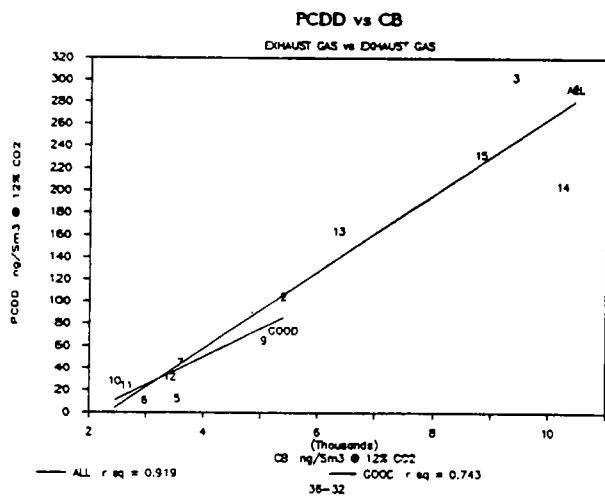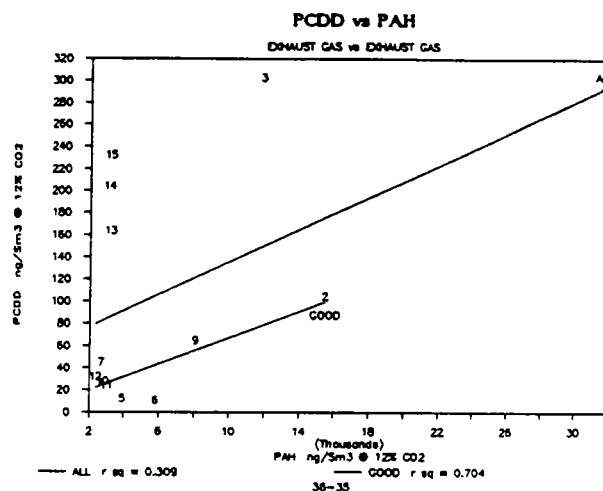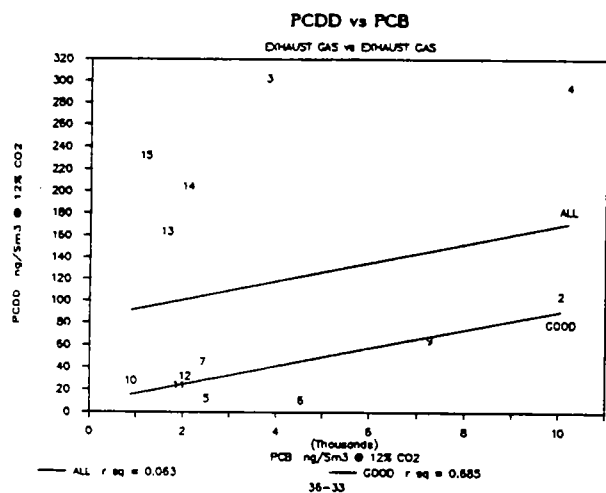
strong relationship may exist between the concentrations of dioxin and potential precursors found in the exhaust emissions.

Interestingly, when only the good Performance Test runs were considered for PAH and PCB, the r^2 values showed strong correlations with dioxin (exhaust concentration). However, when all the Performance Test runs were combined, the correlations failed.

11.3.2   Furan Correlations

As previously discussed for dioxin, significant relationships were also found for furans versus monitoring, operating and other variables.

Operating Variables

The furan correlations in the exhaust gas in comparison with the selected operating variables are shown in Table 11.4. As was the case for dioxins, furans concentrations showed strong correlations with exhaust gas flow and primary air (as shown in Figure 11.5) with r^2 values of 0.76 and 0.68, respectively. Unlike the dioxins, furans showed no correlation with secondary air.

Figure 11.5

PCDD vs PRIMARY AIR
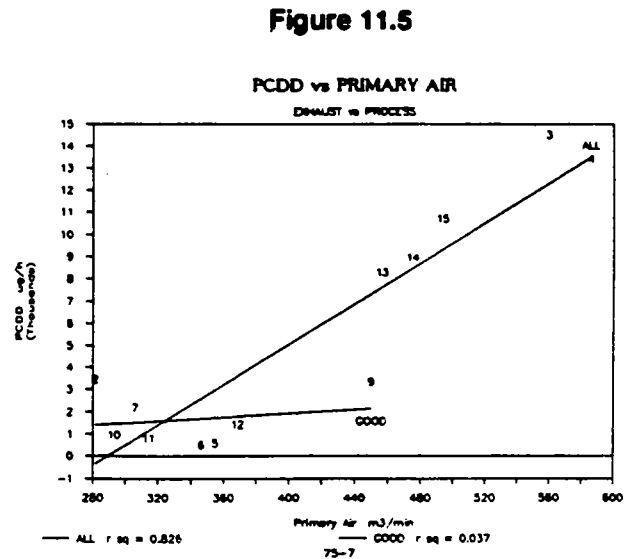
Monitoring Variables

The three combustion parameters (Temperature, retention Time and Turbulence) that were previously discussed as being important factors in dioxin formation and destruction appeared to be equally important to furan formation.

As shown in Figure 11.6 and Table 11.5, no significant correlations appeared to exist between furans and process temperatures.

As anticipated, furan concentrations showed a strong correlation with carbon monoxide concentrations, with an r^2 value of 0.61. However, furan concentrations showed weak correlations with emissions of NO_x, HCl, SO_2 and excess air (O_2), as shown in Table 11.5.

TABLE 11.4
PCDF Correlation
Operating Variables

Correlated Parameters	Determination Coefficients (r^2)
Upper Radiation Chamber Temp. ($^{\circ}$C)	0.25 (No correlation)
Lower Radiation Chamber Temp. ($^{\circ}$C)	0.22 (No)
Boiler Inlet. Temp. ($^{\circ}$C)	0.18 (No)
Exhaust gas flow (Sm^3/min)	0.76 (Very good)
Primary Air (m^3/min)	0.68 (Very good)
Secondary Air (m^3/min)	0.03 (No)

TABLE 11.5
PCDF Correlation
Monitoring Variables

Correlated Parameters	Determination Coefficients (r^2)
Particulate	0.63
Cd	0.70
Cu	0.72
Zn	0.63
Upper Radiation Chamber Temp. ($^{\circ}$C)	0.25 (No correlation)
Lower Radiation Chamber Temp. ($^{\circ}$C)	0.22 (No)
Boiler Inlet. Temp. ($^{\circ}$C)	0.18 (No)
CO	0.61
NO_x	0.28 (No)
HCl	0.14 (No)
SO_2	0.32
Excess Air	0.24 (No)

Figure 11.6 : Furan vs Process Temperature

PCDF vs LOWER RADIATION CHAMBER TEMP.

EXHAUST GAS vs PROCESS

———— ALL r sq = 0.152   ———— GOOD r sq = 0.247

37-9

PCDF vs BOILER INLET TEMP.

EXHAUST GAS vs PROCESS

———— ALL r sq = 0.187   ———— GOOD r sq = 0.160

37-127
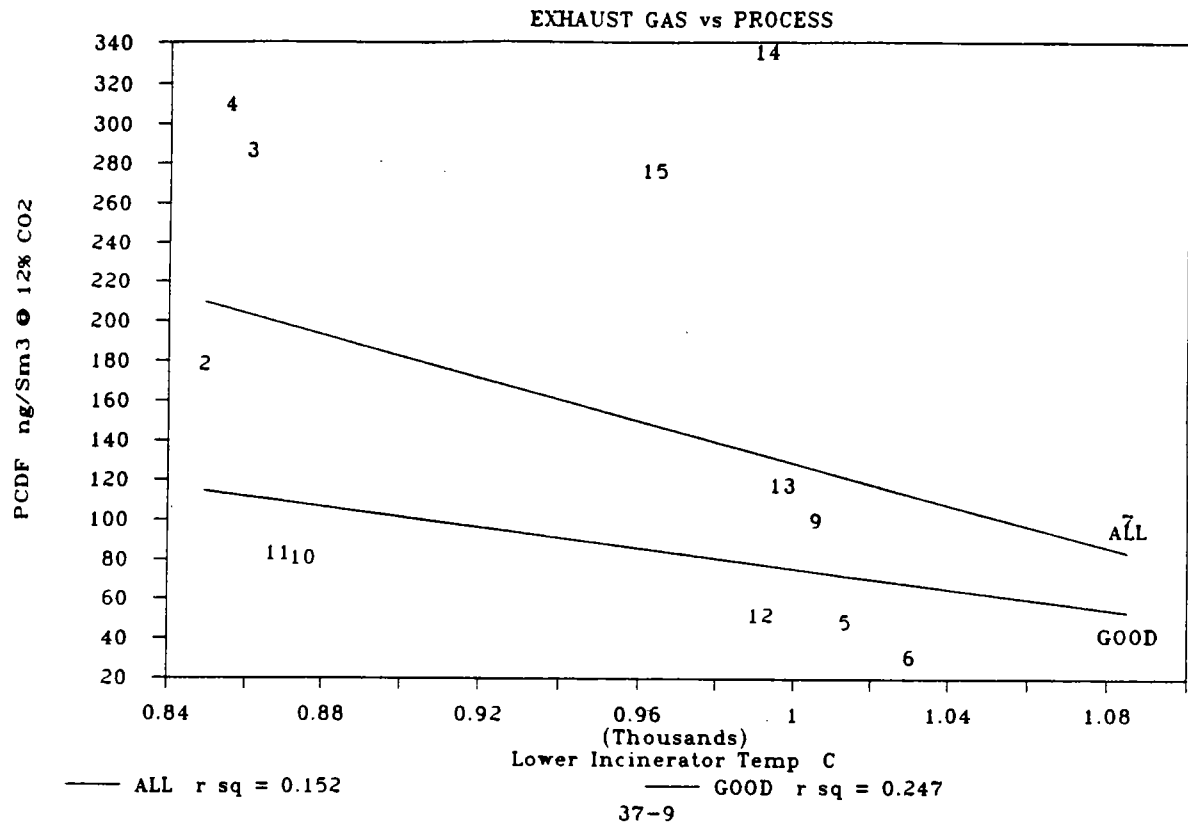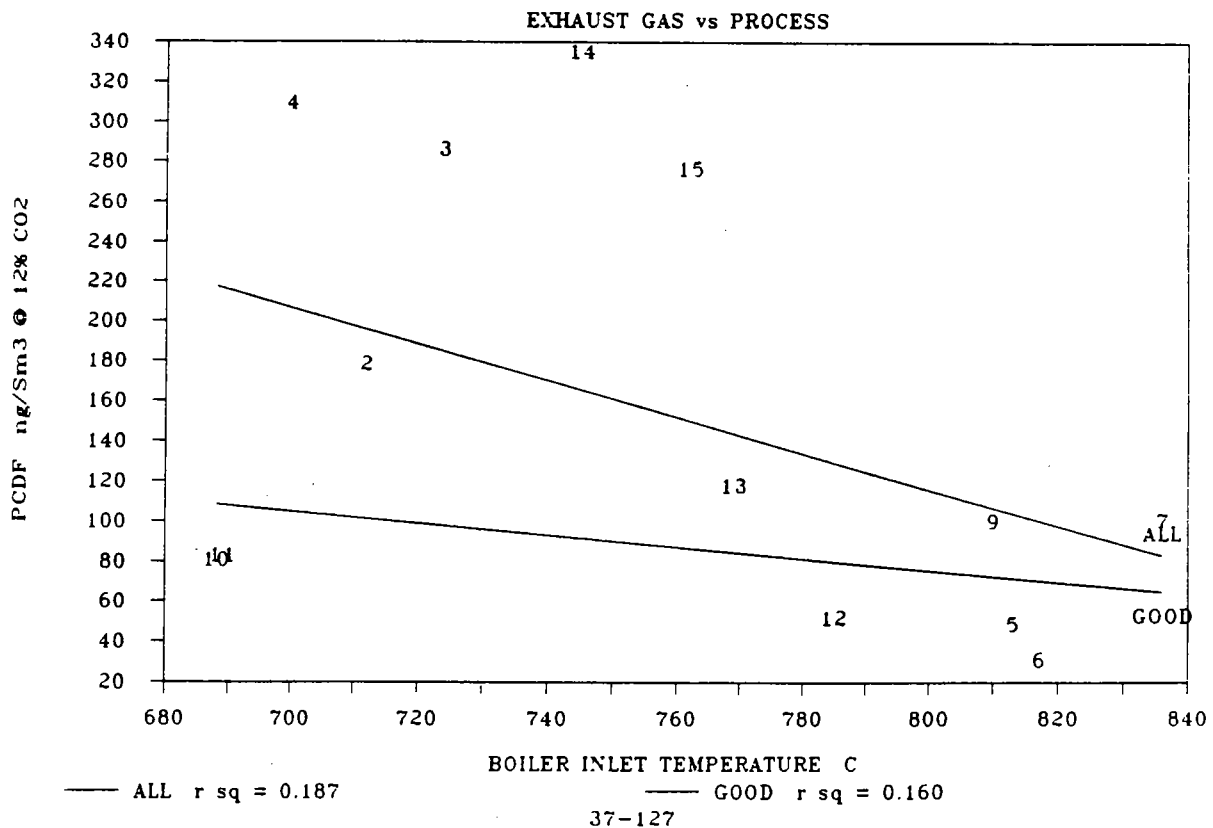
Other Variables

In sub-section 11.3.1, it was mentioned that some metals are thought to act as catalysts in the formation of some trace organics. Trace metal concentrations in the exhaust gases were compared to furan emissions as presented in Figure 11.7 and Table 11.5. Copper (r^2 = 0.72) and cadmium (r^2 = 0.70) showed quite strong correlations and to a slightly lesser degree so did particulate (r^2 = 0.63) and zinc (r^2 = 0.63) emission concentrations.

When furan emissions were compared to other trace organics, some interesting results surfaced. Furan data correlated strongly with dioxin (r^2 = 0.85), chlorobenzene (r^2 = 0.92) and chlorophenol (r^2 = 0.90) emissions, as also shown in Figure 11.8. This trend was also observed with the dioxin data. It appears that strong relationships exist between furan emissions and some potential precursors found in the exhaust gas. No correlations appeared to occur with either PAH or PCB concentrations when all the test runs were considered. However, when only the good test runs were considered, both the PAH and PCB correlations improved (r^2 = 0.58 and r^2 = 0.48, respectively).

Virtually no correlations were found when furans in the refuse versus those in the precipitator ash and the exhaust gas were correlated. This suggests, as in the case of dioxins, that physicochemical reactions may have occurred, changing the structure of furans.

11.3.3 Particulate Emission

The particulate concentration in the exhaust gas was compared to a wide variety of parameters to ascertain if potential correlations existed. Primary air and flue gas flows with r^2 = 0.62 and r^2 = 0.69, respectively, maintained relatively strong correlations. As previously discussed, combustion air flows through the grates have a direct impact on the solids carrying potential of the incineration system. Accordingly, particulate concentrations are expected to vary directly with air flow.

Correlations between particulates and organic emissions in exhaust gases were significant. As discussed in sub-sections 11.3.1 and 11.3.2, good correlations were found with dioxins (r^2 = 0.64) and furans (r^2 = 0.62). In addition, the correlations of CB with particulates was significant (r^2 = 0.67) but to a lesser extent with CP (r^2 = 0.46).

As anticipated, significant correlations were found between particulate emission concentrations and selected trace metal concentrations such as cadmium, copper, and lead. These resulted in very good to excellent correlations with r^2 values of 0.86, 0.94 and 0.90, respectively.

It was observed that the particulate emission rate showed strong correlation with the CO concentration (r^2 = 0.64). This suggests that by reducing the CO concentrations (indicative of good combustion), lower particulate emissions would result.
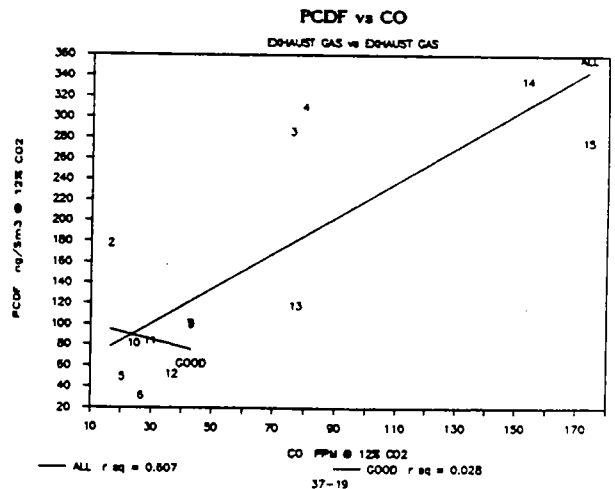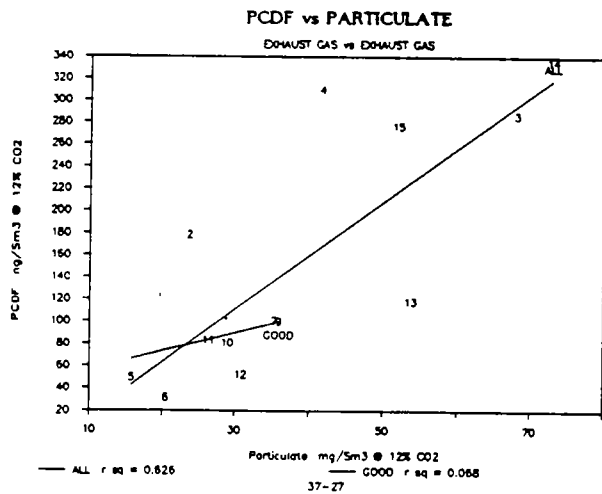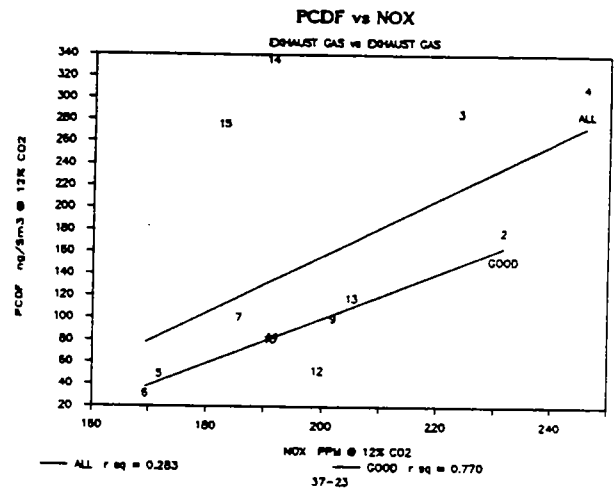
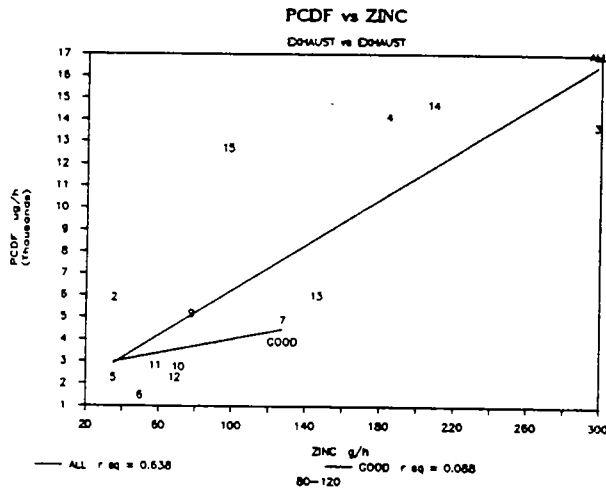# Figure 11.7 : Furan vs Monitoring Variables

PCDF vs COPPER

PCDF vs CADMIUM

PCDF vs ZINC

PCDF vs NOX

PCDF vs PARTICULATE

PCDF vs CO
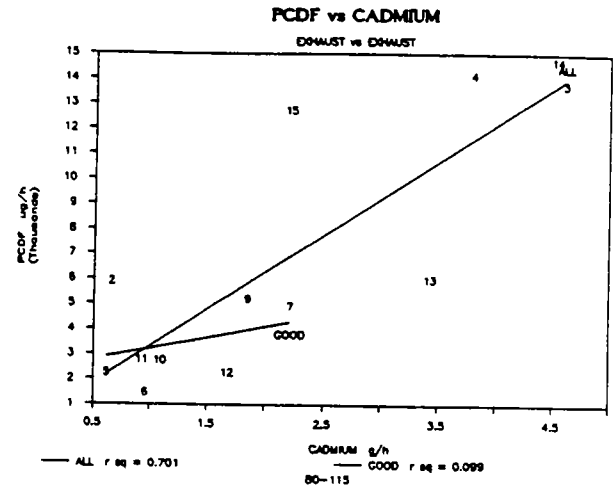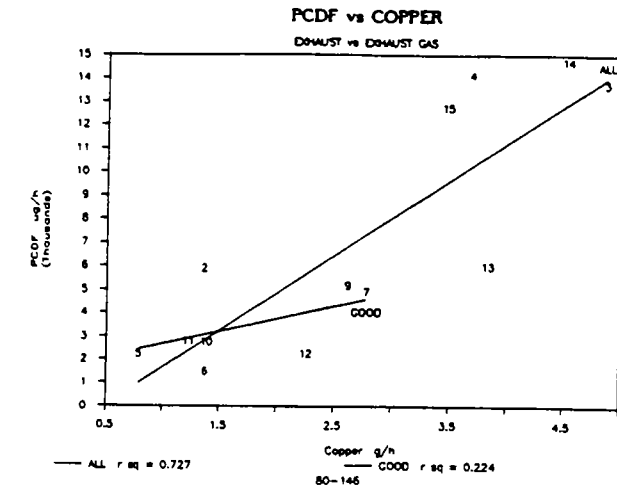
Figure 11.8 : Furan vs Trace Organics

PCDF vs PCDD

ALL r sq = 0.853   GOOD r sq = 0.882
37-36

PCDF vs CB

ALL r sq = 0.917   GOOD r sq = 0.489
37-32

PCDF vs CP

ALL r sq = 0.902   GOOD r sq = 0.808
37-34

PCDF vs PAH

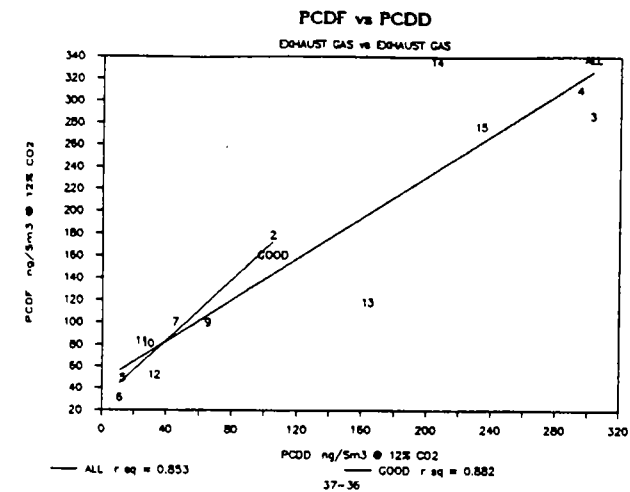ALL r sq = 0.240   GOOD r sq = 0.580
37-35

PCDF vs PCB

ALL r sq = 0.061   GOOD r sq = 0.477
37-33
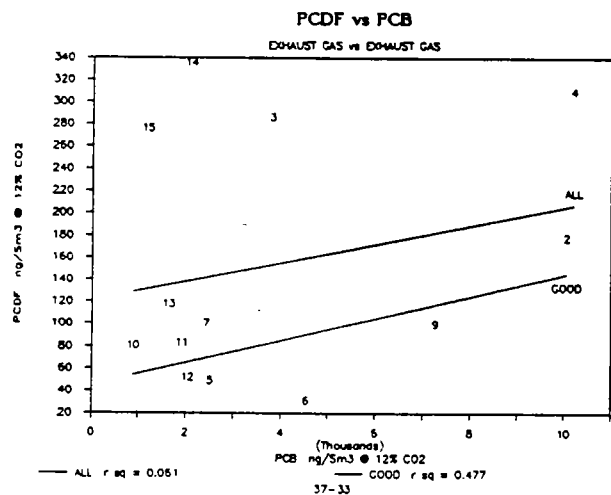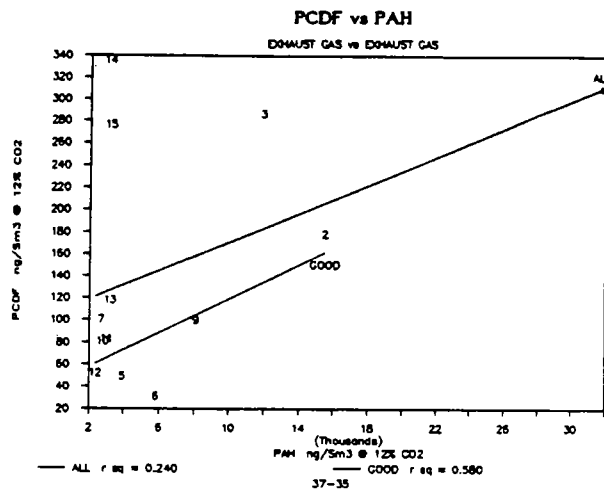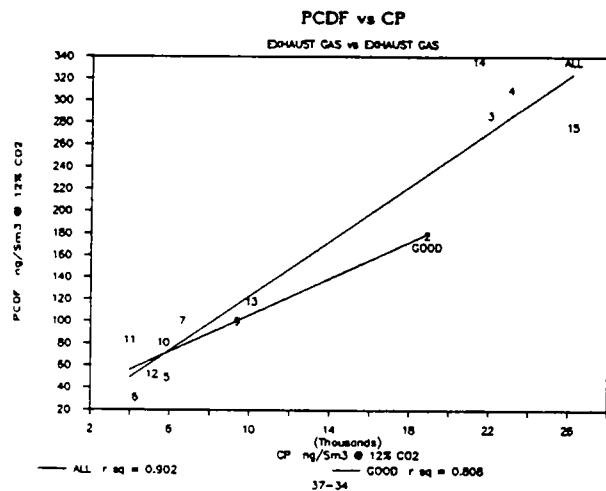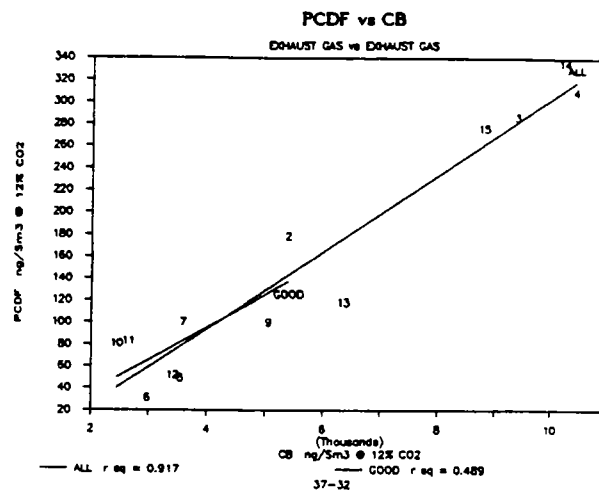
11.3.4 Metals Correlations

As mentioned previously in this chapter, it has been suggested that heavy metals may act as catalysts in the formation of dioxins, furans, CB and CP. Possible catalyst candidates include antimony, cadmium, chromium, copper and zinc. From the data presented in Table 11.6, a number of strong correlations were found which support this theory. For example, dioxins and furans correlate well with 6 of the 9 metals listed in Table 11.6. To a slightly lesser degree, CB and CP also correlated with these metals. However, poor correlations were found when mercury and nickel were compared to all organic data i.e. r^2's 0.1.

No correlations were found for the PAH's and PCB's when compared to any of the metals.

Another avenue explored was the examination of emission rates versus metals in the electrostatic precipitator fly ash. As shown in Table 11.7, chromium, copper, and nickel resulted in strong relationships with all organic emissions, with the exception of PCB's.

Correlations of priority metals in the refuse versus emissions of metals on a rate basis, were all very weak, with the exception of antimony ($r^2 = 0.53$). This suggests that a problem exists in the sampling procedures employed. During testing, oversized pieces of metal were removed prior to shredding and analysis. Improved methods for obtaining representative refuse samples will be required to ensure that accurate metals mass balances can be made.

11.3.5 Combustion Temperature

Combustion temperatures (boiler inlet and furnace radiation chamber) are considered to be very important parameters in incinerator operation and consequently provided some very significant correlations.

Furnace radiation chamber and boiler inlet temperatures correlated very well with O_2 and CO_2 concentrations, as shown in Figure 11.9. The exhaust gas O_2 concentration correlated inversely with process temperatures, while CO_2 produced a directly proportional correlation.

No correlations were found with any of the priority metals.

As discussed in sub-sections 11.3.1 and 11.3.2, combustion temperatures correlated poorly with all organic emissions.

TABLE 11.6

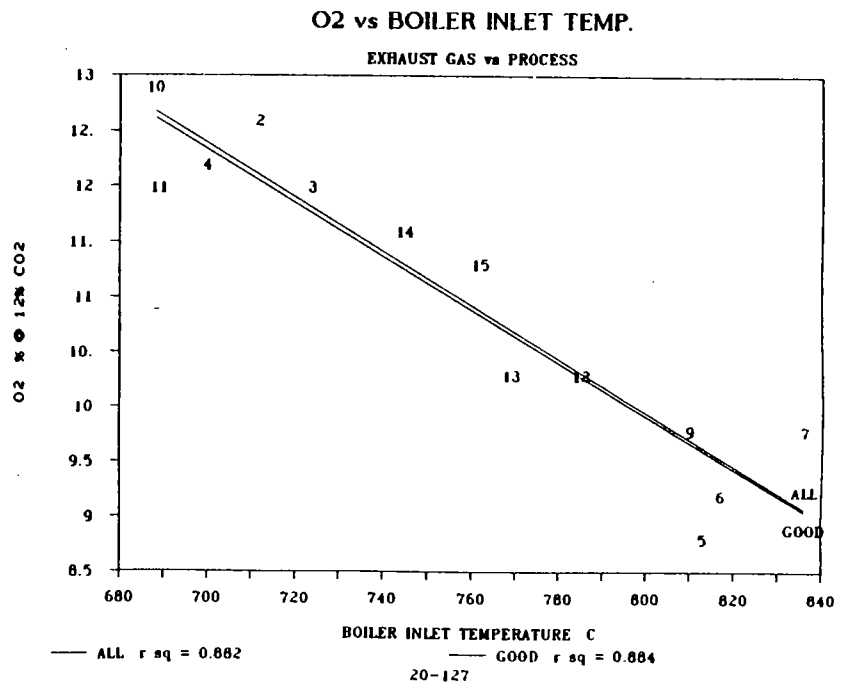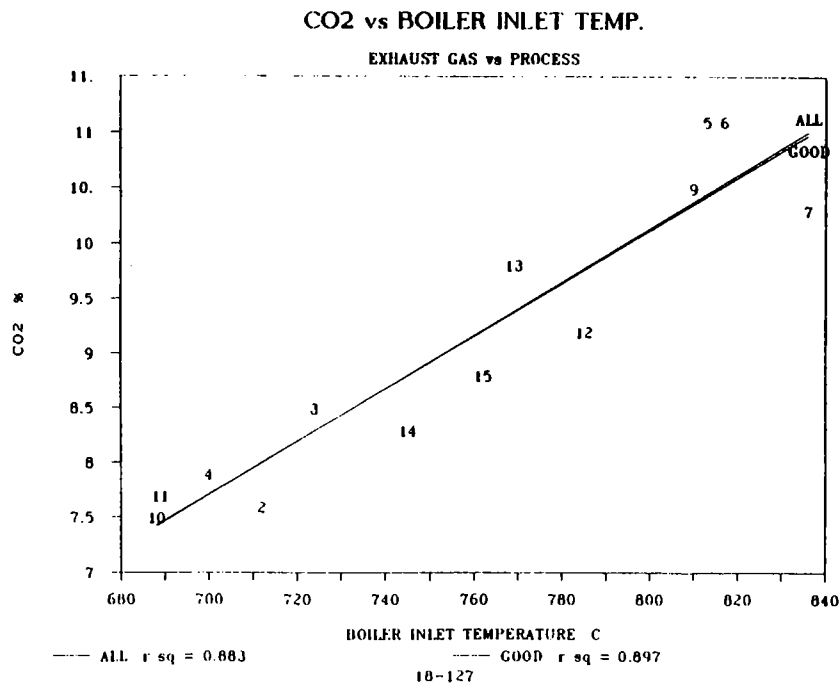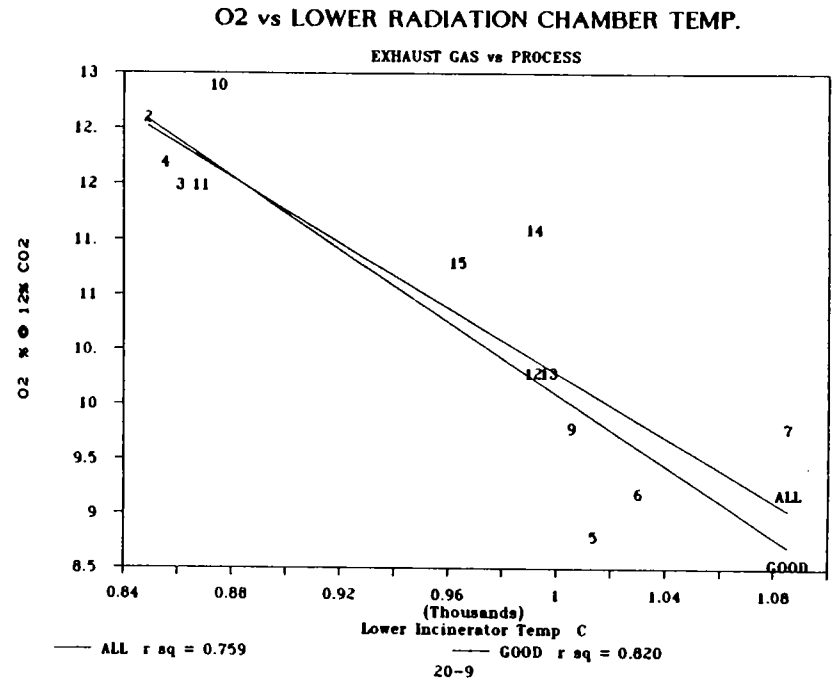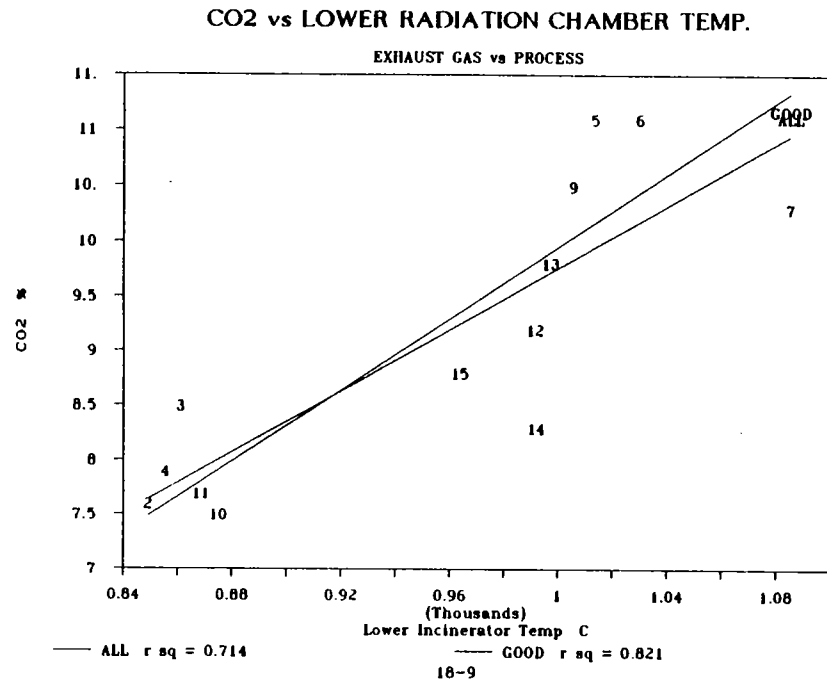## EXHAUST EMISSION METALS DETERMINATION COEFFICIENT (r^2)

	Sb g/h	As g/h	Cd g/h	Cr g/h	Cu g/h	Pb g/h	Hg g/h	Ni g/h	Zn g/h
PCDD (ng/h)	0.77	0.35	0.74	0.59	0.77	0.48	0.01	0.11	0.70
PCDF (ng/h)	0.54	0.43	0.70	0.44	0.72	0.52	0.00	0.05	0.63
CB (ng/h)	0.65	0.38	0.77	0.55	0.34	0.58	0.03	0.11	0.64
CP (ng/h)	0.50	0.31	0.51	0.41	0.61	0.40	0.00	0.07	0.45
PAH (ng/h)	0.06	0.03	0.13	0.14	0.08	0.00	0.10	0.01	0.13
PCB (ng/h)	0.00	0.00	0.01	0.08	0.00	0.00	0.09	0.09	0.00

TABLE 11.7

CORRELATIONS BETWEEN ORGANIC EXHAUST EMISSIONS VS METAL IN PRECIPITATOR ASH

Exhaust Emissions	Precipitator Ash								
	Antimony	Arsenic	Cadmium	Chromium	Lead	Mercury	Nickel	Zinc	Copper
PCDD	.39	.01	.26	.72	.41	.08	.76	.42	.64
PCDF	.17	.03	.12	.55	.27	.11	.70	.28	.76
CB	.25	.00	.35	.69	.53	.20	.85	.43	.74
CP	.18	.01	.11	.55	.30	.07	.63	.28	.48
PAH	.04	.01	.10	.49	.08	.00	.13	.46	.18
PCB	.00	.16	.05	.26	.05	.00	.02	.31	.08

Figure 11.9 : Combustion Temperature Correlation

CO2 vs LOWER RADIATION CHAMBER TEMP.

EXHAUST GAS vs PROCESS

ALL r sq = 0.714   GOOD r sq = 0.821

18-9

O2 vs LOWER RADIATION CHAMBER TEMP.

EXHAUST GAS vs PROCESS

ALL r sq = 0.759   GOOD r sq = 0.820

20-9

CO2 vs BOILER INLET TEMP.

EXHAUST GAS vs PROCESS

ALL r sq = 0.883   GOOD r sq = 0.897

18-127

O2 vs BOILER INLET TEMP.

EXHAUST GAS vs PROCESS

ALL r sq = 0.882   GOOD r sq = 0.884

20-127

11.3.6 Process Air Flow Correlation

Correlations of contaminants at the precipitator inlet or outlet versus process air flows (i.e. primary air, secondary air, and total exhaust gas) were made to assess their impact. This data is presented in Table 11.8.

TABLE 11.8
CONTAMINANT EMISSION RATE VERSUS PRIMARY AIR AND EXHAUST GAS FLOW

| Dependent Variables | Determination Coefficient (r^2) | | | |
	Primary Air m^3/min	Precip. Inlet Exhaust Gas Flow $m^3/min.$	Primary Air $m^3/min.$	Precip. Outlet Exhaust Gas Flow $m^3/min.$
PCDD (ug/h)	N/A	N/A	0.82	0.87
PCDF (ug/h)	N/A	N/A	0.68	0.76
CB (ug/h)	N/A	N/A	0.87	0.83
CP (ug/h)	N/A	N/A	0.66	0.67
PAH (ug/h)	N/A	N/A	0.33	0.30
PCB (ug/h)	N/A	N/A	0.11	0.07
Antimony (g/h)	0.35	0.35	0.67	0.75
Arsenic (g/h)	0.01	0.00	0.28	0.48
Cadmium (g/h)	0.47	0.40	0.68	0.83
Chromium (g/h)	0.81	0.76	0.61	0.71
Copper (g/h)	0.76	0.70	0.69	0.74
Lead (g/h)	0.54	0.47	0.48	0.58
Mercury (g/h)	0.02	0.04	0.01	0.03
Nickel (g/h)	0.79	0.83	0.15	0.13
Zinc (g/h)	0.46	0.44	0.58	0.73
Particulate g/h	0.14	0.86	0.62	0.76

As previously mentioned, organic emissions of PCDD, PCDF, CP and CB correlated very well with primary air flow. The r^2 values ranged between 0.66 and 0.87. On the other hand, PAH and PCB showed poor correlations, with r^2 values between 0.11 and 0.33.

Chromium, copper and nickel correlated well with primary air and exhaust gas flow at the precipitator inlet as shown in Table 11.8. Strong correlations with precipitator outlet flows occurred with metal such as antimony, cadmium, chromium, copper and zinc.

An important and expectedly strong correlation occurred when the exhaust gas flow was compared to the particulate emission at both the inlet and outlet of the precipitator, with $r^2 = 0.86$ and $r^2 = 0.76$, respectively.

Secondary air flows showed very weak correlations with the emission of both organics and metals.

Although emissions were found to correlate better with primary air than secondary air, the subsequent discussion of the multiple regression analysis will demonstrate the importance of having a proper primary/secondary air split.

11.3.7   Continuous Gas Emissions Correlations

Carbon Monoxide

Figure 11.10 shows the correlation of a number of trace organic emissions in the exhaust gas versus carbon monoxide (CO). In addition to the relatively strong correlations found between PCDD and CO, and PCDF and CO (as discussed in 11.3.1 and 11.3.2), similar correlations were also found for CB and CP versus CO. Generally, it has been suggested that a relationship may exist between trace organics emissions and carbon monoxide levels. For PCDD and PCDF, these results to some degree tend to corroborate this theory. Other important organics such as PAH and PCB, showed no correlation. It should be noted that no correlations occurred between CO and trace organics when only "good" operating condition test results were considered. This is attributed to the fact that under the good conditions, the data tended to cluster near 50 ppm, making correlations difficult.

When CO was compared with primary air and exhaust gas flow, no correlations existed.

Nitrogen Oxides

Emissions of nitrogen oxides from refuse incineration would be expected to fluctuate and to be strongly influenced by the combustion chamber temperature. Determination coefficients for nitrogen oxide emissions versus the following temperatures are summarized below:

Temperature	r^2
Lower Radiation Chamber	0.44
Upper Radiation Chamber	0.37
Boiler Inlet	0.31

The above coefficients suggest that relatively weak correlations existed between NO_x emissions and these furnace temperatures.

Figure 11.10 : Carbon Monoxide Correlation

PCDD vs CO

PCDF vs CO

CP vs CO

CB vs CO

PCB vs CO

PAH vs CO
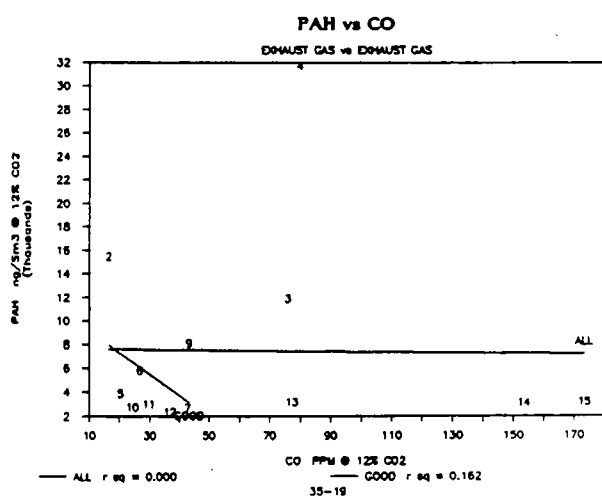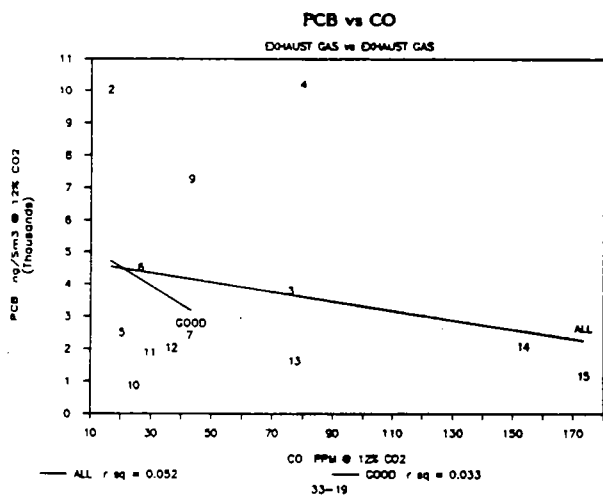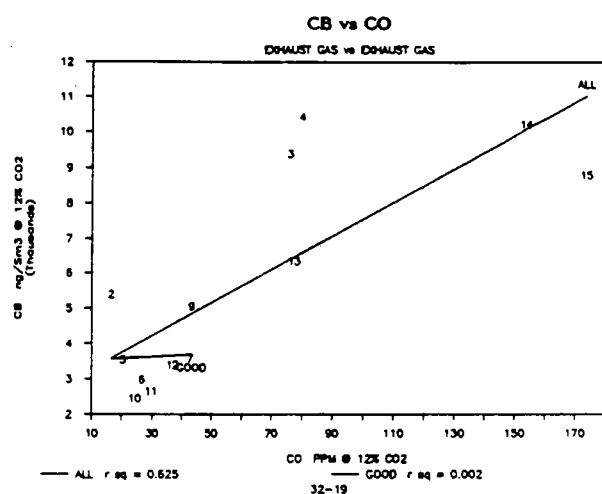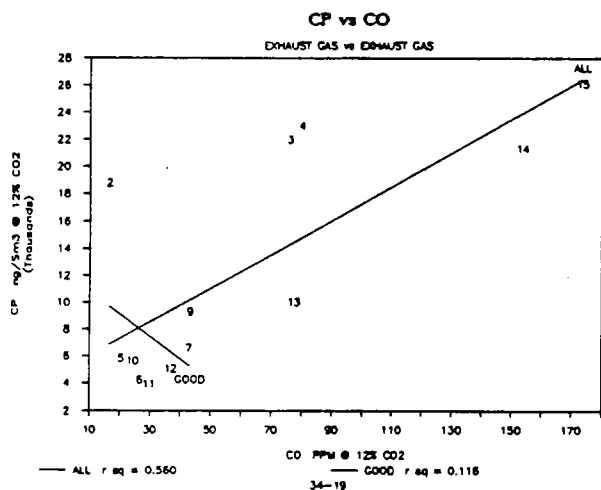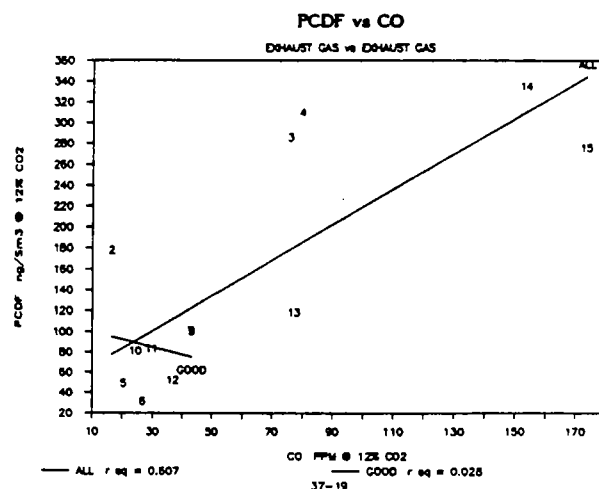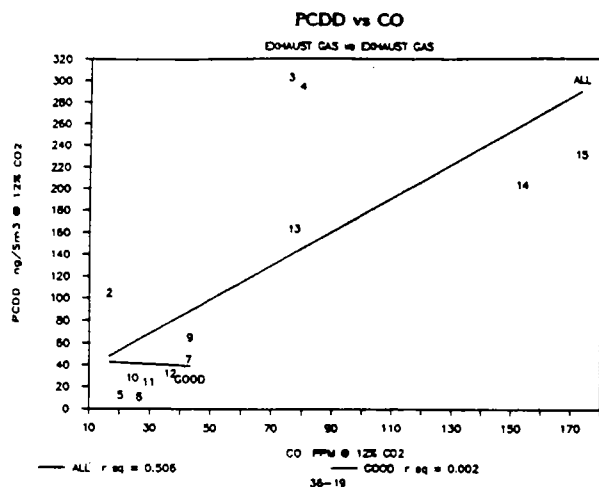
Interesting correlation results for NO_x did occur, however, during the multiple linear regression analysis work (Section 11.4).

Hydrochloric Acid

Although it is generally accepted that hydrochloric acid emissions vary directly with the chlorine content of the refuse, the results from this program indicated that no correlation existed.

When the HCl exhaust concentrations were compared to the trace organic emissions, the following r^2 values were calculated:

HCl Correlation

Parameters	(r^2)
PCDD vs. HCl	0.05
PCDF vs. HCl	0.14
PCB vs. HCl	0.01
CB vs. HCl	0.08
CP vs. HCl	0.09
PAH vs. HCl	0.01

Again as indicated from the above comparison, no apparent correlation existed between HCl and the trace organic emissions.

Sulphur Dioxide

As in the case of HCl, correlations between SO_2 emissions versus the process parameters, trace organics and inorganics emissions were very poor. For example, the r^2 value calculated for trace organic emissions versus SO_2 emissions was between 0.15 and 0.36. The rationale for these poor correlations is similar to that suggested for HCl.

Excess Air

Correlations between excess air and those parameters which demonstrated strong correlations are listed below. As expected, excess air correlated well with process temperatures, CO_2, O_2 and moisture since they are somewhat interrelated. The determination coefficients calculated for excess air versus other emission parameters, such as CO, trace organics, and metals, showed no correlation.

EXCESS AIR CORRELATIONS

Parameters	r^2
CO_2 (%)	0.91
Flue Gas Moisture (%)	0.71
O_2 (%)	0.99
Upper Radiation Chamber Temp. (^oC)	0.76
Lower Radiation Chamber Temp. (^oC)	0.83

11.4 MULTIPLE LINEAR REGRESSION ANALYSIS - ORGANICS EMISSIONS

11.4.1 Overview

To continue on from simple regression analysis, multiple linear regression analysis was undertaken. The coefficients of determination obtained from the multiple regression models for trace organic emissions are summarized in Table 11.9. These results indicate that a significantly better fit was achieved with the majority of the data. The multiple regression models resulted in r^2 values of 0.8 to 0.9 for dioxins, furans, CP and CB as compared to the range of 0.5 to 0.8 for single regression. This indicates that the multiple regression models are potentially more useful in identifying the primary variables which can be used to predict and to control concentrations of dioxin, furan, CP and CB. These findings are further discussed below.

TABLE 11.9
SUMMARY OF DETERMINATION COEFFICIENTS
FOR REGRESSION MODELS

Type of Organic	Simple Regression		Multiple Regression	
	Prediction Models	Control Models	Prediction Models	Control Models
Dioxin	0.51	0.77	0.89	0.89
Furan	0.61	0.55	0.90	0.84
CP	0.56	0.50	0.86	0.77
CB	0.62	0.67	0.87	0.82
PAH	0.67	0.40	0.73	0.63
PCB	0.54	0.16	0.62	0.27

Multiple regression correlations were generated using from 2 to a maximum of 6 variables. Variables were added in an attempt to improve the models (i.e. improve the correlation to better predict concentrations. Variables which failed to increase the coefficient of determination (r^2) by at least 0.01 over the previous model were rejected as producing no significant improvement to the fit.

The final number of variables used in the "best fit" models were based on the experience and judgement of the reviewers. In a majority of the cases, three variable models were chosen as being adequate. In a few cases, two variable models were selected, since additional variables made no significant improvement to this model.

Operating variables in the **control model** were chosen based on the requirement to represent the basic three "T's" of combustion - residence Time, Temperature and Turbulence. **Control models** that included more variables than were necessary to represent the three "T's" of combustion were rejected due to redundancy in the variables. This resulted in three variable equations being selected for most models and some two variable equations, as mentioned above.

The **prediction models** employed were divided into two sets:

a)   those that included NO$_x$, and

b)   those that did not.

This division was primarily made due to the uncertainty as to the significance of NO$_x$ in the equation.

The **control models** were also divided into two sets:

a)   those that used steam rate, and

b)   those that used refuse feed rate.

The very high correlation between steam rate and refuse feed rate precluded treating them as independent of one another.

The graphs in this section show a straight, diagonal line to mark the position of a perfect match between the measured and calculated values. The numbers plotted on the graphs mark the actual values obtained. The models for each of the organics examined can be better understood by examining these graphs. The closer the numbers approach the diagonal, the stronger the model.

Two parallel lines have been placed on each side of the diagonal of these graphs: one above and one below the "perfect fit" diagonal. These lines are each displaced from the perfect fit by a distance equal to the average of the absolute values of all the residuals. The band formed by these lines is called the residual band and is used to visually represent the r^2 value. The residual band has no statistical significance beyond the purpose of visual comparisons between correlations models.

The narrower the residual band, the closer the numbers approach the diagonal and, therefore, the higher the r^2 values and the stronger the model. As more variables are added to a model, the residual band should become narrower else the model should be rejected. A wide residual band indicates a poor model. The data points 2 to 15 correspond to the Performance Test runs PT-02 to PT-15.

Further details pertaining to the relationship between trace organics and the operating and monitoring variables are presented in the following sections.

The accompanying tables show the progressive increase in r^2 achieved by going from a one-variable model to a two-variable model and then the three- variable model. The regression coefficients for the best fit model are highlighted in each table and the best fit equations resulting from these regression coefficients are shown at the bottom of each table.

11.4.2 Dioxins

The prediction model for dioxins which employed NO_x, carbon monoxide and moisture in the flue gas, resulted in one of the highest r^2 values (0.89). This model, as shown in Figure 11.11A, fits evenly and closely around the diagonal line, as indicated by the narrow residual band, with the exception of test point 3 (PT-03). PT-03 is well below the line, indicating that the model predicts a lower dioxin concentration than was actually measured for this run. Despite the effect of this test point on the model, all the other test points fit exceptionally well.

A similar **prediction model** without using the nitrogen oxides data, did not fit as tightly to the line, as shown in Figure 11.11B and demonstrated by the wider residual band. PT-03, -04,-07 and -11 fit as poorly as did PT-03 on Figure 11.11A, which would explain the lower r^2 value (0.74). The points form a band centered on the diagonal and the band is of roughly equal width over the full range of dioxin values. This would indicate that the assumption of a linear relationship is correct. As shown in Table 11.10, the model with (11.10A) and without (11.10B) nitrogen oxide employed carbon monoxide as the primary variable.
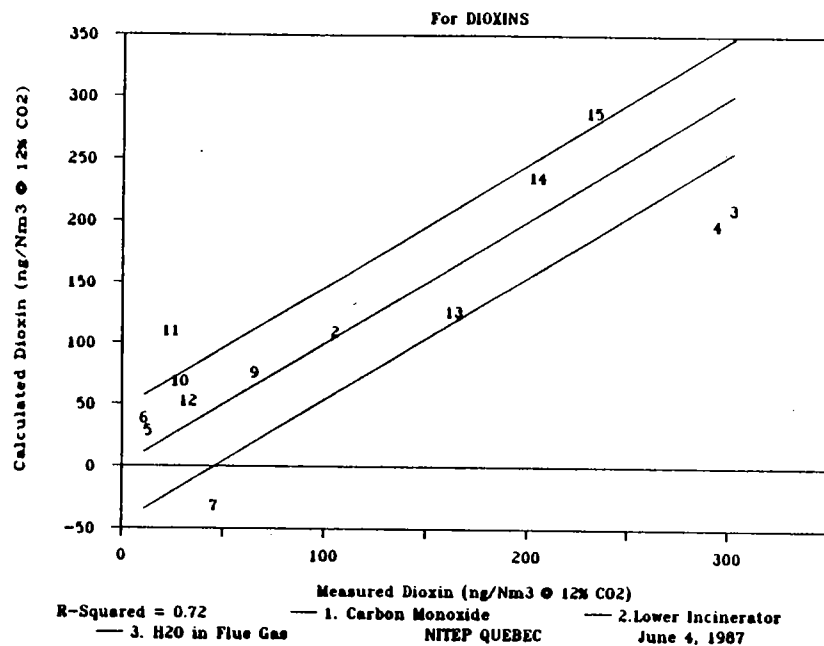
The **control model** for dioxin is shown in Figure 11.11C. This model fits as closely to the line as the NO_x **prediction model**, as can be seen by comparing the widths of the residual bands. The strong correlation (r^2 of 0.89) obtained with this model suggests that the dioxin emissions can be controlled by the appropriate adjustments of the total air flow, primary/ secondary ratio and the steam rate.

On all three figures discussed, the test points representing poor operating conditions (3, 4, 14 and 15) are located in the upper right corner of the graph. This is the region of the highest dioxin emissions as well. As anticipated, the poor operating conditions produced higher levels of dioxins.

Further details pertaining to the relationship between dioxins and the operating and monitoring variables can be found in Table 11.10. From Table 11.10A, it can be shown that an increase of either carbon monoxide, NO_x or moisture in the flue gas would indicate an increase in dioxin emissions. However, in Table 11.10B where NO_x was not used, the data suggests that a decrease in lower radiation chamber temperature, or an increase in CO and moisture would indicate an increase in dioxin. The **control model** in Table 11.10C indicates that increasing the total air flow or the primary/ secondary air ratio will result in an increase in dioxin. These findings suggest that modelling may be an effective means of using both operating and monitoring variables for seeding and eventually controlling emissions of concern.

Figure 11.11 : Dioxins Correlation

A Best 3 Monitoring Variable Model

For DIOXINS

R-Squared = 0.72 — 1. Carbon Monoxide — 2.Lower Incinerator
— 3. H2O in Flue Gas   NITEP QUEBEC   June 4, 1987

B Best 3 Monitoring Variable Model

For DIOXINS

R-Squared = 0.89 — 1. Carbon Monoxide — 2. Nitrogen Oxides
— 3. H2O in Flue Gas   NITEP QUEBEC   July 6, 1987

C Best 3 Operating Variable Model

for Dioxin

R-Squared = 0.89 — 1. Total Comb. Air — 2. Prim./Sec. Air
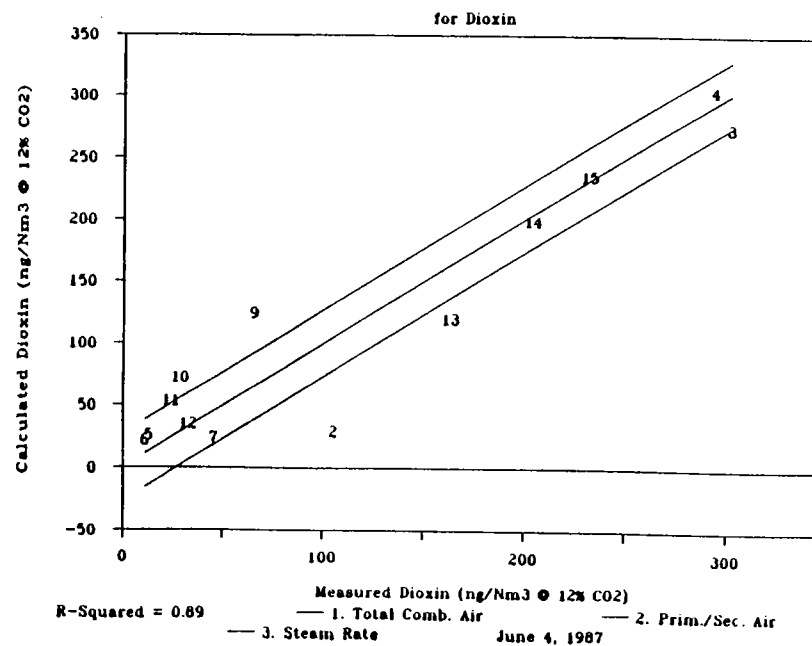— 3. Steam Rate   June 4, 1987
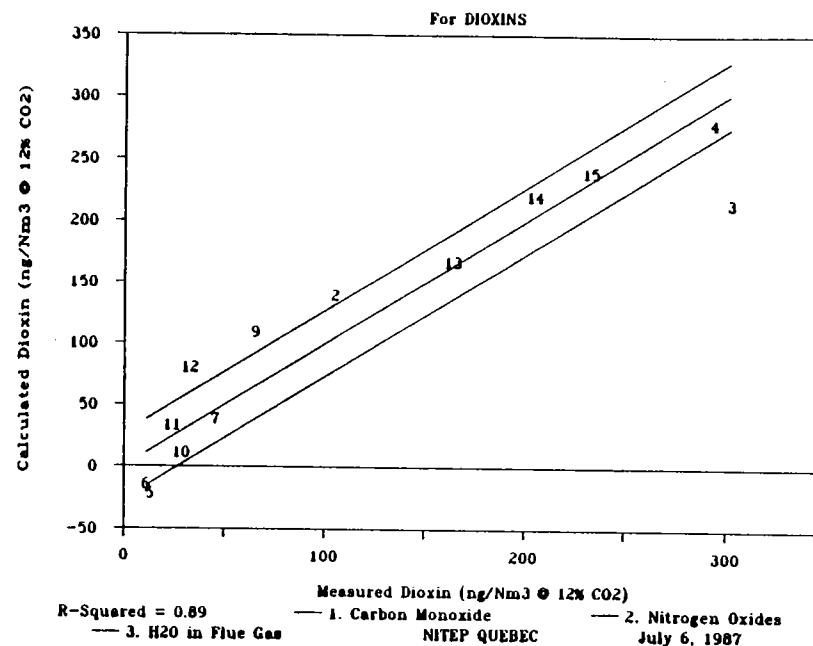
Table 11.10
TOTAL PCDD CORRELATIONS

A. TOTAL PCDD (ng/Sm3 @ 12% CO2) vs MONITORING VARIABLES
    NITROGEN OXIDES as a variable

VARIABLE	UNITS	1	2	3	4
r2			0.51	0.88	0.89	0.91
CARBON MONOXIDE	ppm	1.55	1.52	1.58	1.68
NITROGEN OXIDES	ppm		2.93	3.10	2.86
MOISTURE IN THE FLUE GAS	%			8.30	
OXYGEN IN THE FLUE GAS (DRY)	%				-32.9
LOWER RADIATION CHAMBER TEMP.	deg C				-0.545
INTERCEPT		22.1	-561	-717	324
C(p)		28.0	2.08	3.38	4.01

Best Fit Prediction Equation
Total PCDD = Carbon Monoxide x 1.58 + Nitrogen Oxides x 3.10 + Moisture in Flue Gas x 8.30 - 717

B. TOTAL PCDD (ng/Sm3 @ 12% CO2) vs MONITORING VARIABLES
    NITROGEN OXIDES variable not used

VARIABLE	UNITS	1	2	3	4
r2			0.51	0.69	0.72	0.72
CARBON MONOXIDE	ppm	1.55	1.53	1.66	1.66
LOWER RADIATION CHAMBER TEMP.	deg C		-0.58	-0.793	-0.815
MOISTURE IN THE FLUE GAS	%			19.4	18.5
OXYGEN IN THE FLUE GAS (DRY)	%				-2.03
INTERCEPT		22.1	577	492	548
C(p)		5.15	2.00	3.00	5.00

Best Fit Prediction Equation
Total PCDD = Carbon Monoxide x 1.66 - Radiation Chamber Temp. x 0.793 + Moisture in Flue Gas x 19.4 + 54

C. TOTAL PCDD (ng/Sm3 @ 12% CO2) vs OPERATING PARAMETERS
    STEAM RATE INCLUDED

VARIABLE	UNITS	1	2	3	4
r2		0.77	0.82	0.89	0.89
PRIMARY AIR FLOW	m3/min	0.93			
TOTAL AIR FLOWS	m3/min		0.59	0.69	0.70
PRIMARY/SECONDARY AIR DIST. RATIO			28.60	32.6	30.50
STEAM RATE	Tonnes/hr.			-7.85	-7.67
SECONDARY F/R COMB. AIR DIST. RATIO					-15.70
SECONDARY AIR FLOW	m3/min				
INTERCEPT		-260	-324	-190	-192
C(p)		4.65	3.77	1.54	3.37

Best Fit Control Equation
Total PCDD = Total Air Flows x 0.694 + Primary/Secondary Air Ratio x 32.6 - Steam Rate x 7.67 - 190

286

11.4.3 Furans

The **prediction model** for furans including NO_x data, resulted in a very high r^2 value (0.90). The variables used in this model are the same three that were used for predicting dioxin: NO_x, carbon monoxide and the percent moisture in the flue gas and are shown in Figure 11.12 and Table 11.11. As seen in Figure 11.12A, this model produces a close fit to the data as indicated by the narrow residual band and the even distribution of residuals along the full length of the line.

The **prediction model** for furan generated without NO_x resulted in a lower r^2 value (0.81) than the model involving NO_x, however this value is still very good. Only two variables were used in this model, carbon monoxide and lower incinerator temperature. These two variables were also chosen for predicting dioxin when NO_x was not considered. Although the moisture in the flue gas improved the predictive capability of the dioxin model, the furan model showed an insignificant improvement when this variable was added to the model.

The **control model** for furans, as shown in Figure 11.12B, resulted in a high r^2 value (0.84) and used the same three variables that were used to control dioxin. These variables were primary/secondary ratio, total air flow and steam rate.

As with dioxins, the upper right corner of both furan graphs contain all four points representing poor operating conditions. This further confirms the assumption made in the dioxin discussion concerning the expectation of higher levels with poor operating conditions.

A review of the data shown in Table 11.11 reveals similar findings to those shown in Table 11.10 for the dioxins. For example, a combination of the three variables, carbon monoxide, NO_x and moisture in the flue gas, can provide a good prediction of dioxins and furans. Similarly, a combination of adjustments to total air flow, primary/secondary air ratio and steam rate can provide a means to control both furan and dioxin emissions.
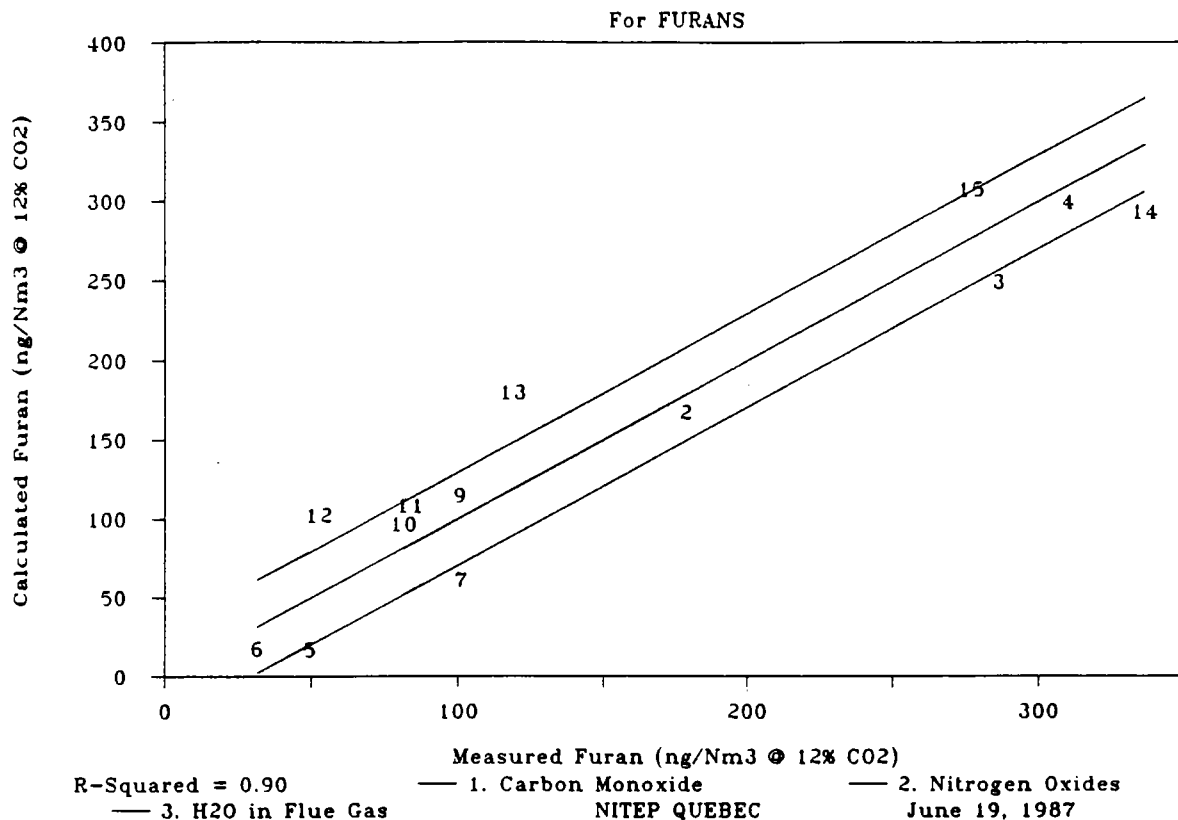
11.4.4 Chlorophenols (CP) and Chlorobenzenes (CB)

The **prediction models** for chlorophenol and chlorobenzene involving NO_x resulted in the best r^2 values (0.86 and 0.87, respectively) as shown in Figure 11.13. The variables used in this model include the same two that were used for predicting dioxins and furans: NO_x and carbon monoxide. The third variable for CP was lower radiation chamber temperature whereas the CB model used oxygen. The models in Figures 11.13A and C produced a close fit to the data, as indicated by the narrow residual bands and consistent residuals along the full length of the line. As previously seen for dioxin and furan, the CP and CB models excluding NO_x also showed a lower correlation than the models including NO_x.

The **control models** for chlorophenol and chlorobenzene, as shown in Figures 11.13B and D, resulted in lower but still strong r^2 values (0.77 and 0.82, respectively) using two of the same three variables

Figure 11.12 : Furans Correlation

A Best 3 Monitoring Variable Model

For FURANS

R-Squared = 0.90   —— 1. Carbon Monoxide   —— 2. Nitrogen Oxides
—— 3. H2O in Flue Gas   NITEP QUEBEC   June 19, 1987

B Best 3 Operating Variable Model

for Furan

R-Squared = 0.84   —— 1. Total Comb. Air   —— 2. Prim./Sec. Air
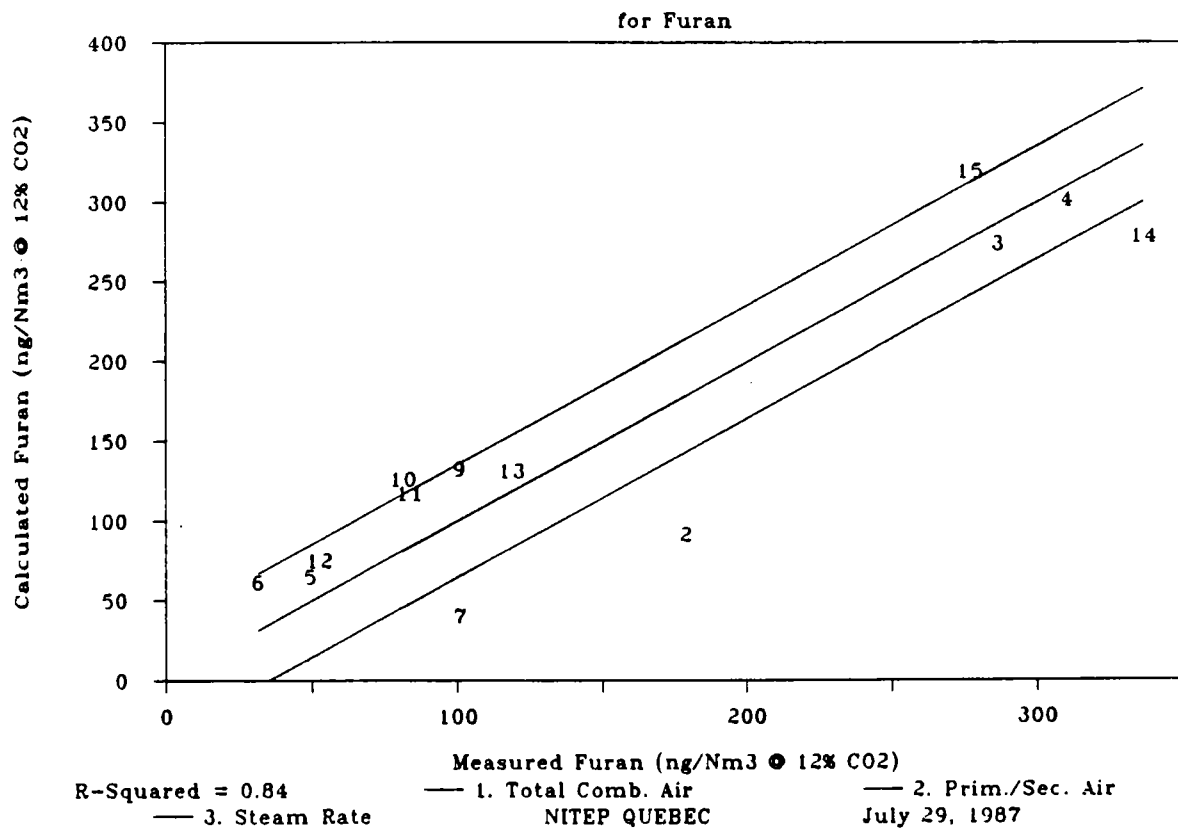—— 3. Steam Rate   NITEP QUEBEC   July 29, 1987

Table 11.11
Total PCDF Correlations

A. TOTAL PCDF (ng/Sm3 @ 12% CO2) vs MONITORING VARIABLES
NITROGEN OXIDES as a variable

VARIABLE	UNITS	1	2	3	4
r2		0.61	0.88	0.90	0.90
CARBON MONOXIDE	ppm	1.70	1.68	1.68	1.63
NITROGEN OXIDES	ppm		2.51	1.90	1.95
LOWER RADIATION CHAMBER TEMP.	deg C			-0.264	-0.182
MOISTURE IN FLUE GAS	%				-6.66
CONTINUOUS FLUE GAS OXYGEN (DRY)	%				
INTERCEPT		49.7	-450	-76.1	-66.9
C(p)		27.3	4.20	4.33	5.96

Best Fit Prediction Equation
Total PCDF = Carbon Monoxide x 1.68 + Nitrogen Oxides x 1.90 - Radiation Chamber Temp. x 0.264 - 76.1

B. TOTAL PCDF (ng/Sm3 @ 12% CO2) vs OPERATING PARAMETERS
STEAM RATE INCLUDED

VARIABLE	UNITS	1	2	3	4
r2		0.55	0.74	0.84	0.86
PRIMARY AIR FLOW	m3/min	0.79			-0.724
PRIMARY/SECONDARY AIR DIST. RATIO			63.80	39.9	58.8
SECONDARY AIR FLOW	m3/min		1.12		
TOTAL AIR FLOWS	m3/min			0.591	1.04
STEAM RATE	Tonnes/hr.			-10.3	-10.20
SECONDARY F/R COMB. AIR DIST. RATIO					
INTERCEPT		-166	-261	-39.4	-78.6
C(p)		14.1	6.47	3.30	4.01

Best Fit Control Equation
Total PCDF = Total Air Flows x 0.591 + Primary/Secondary Air Ratio x 39.9 - Steam Rate x 10.3 - 39.4

Figure 11.13 : CP & CB Correlations

A Best 3 Operating Variable Model

for CHLOROPHENOLs

R-Squared = 0.77 — 1. Total Comb. Air — 2. Prim/Secnd Ratio
— 3. Steam Rate   NITEP QUEBEC   July 29, 1987

B Best 3 Monitoring Variable Model

For CHLOROPHENOLs

R-Squared = 0.86 — 1. Carbon Monoxide — 2. Nitrogen Oxides
— 3. Lower Inc. Temp.   NITEP QUEBEC   July 29, 1987

C Best 3 Operating Variable Model

for CHLOROBENZENEs

R-Squared = 0.82 — 1. Total Comb. Air — 2. Prim/Secnd Ratio
— 3. Secnd F/R Ratio   NITEP QUEBEC   July 29, 1987

D Best 3 Monitoring Variable Model

For CHLOROBENZENEs

R-Squared = 0.87 — 1. Carbon Monoxide — 2. Nitrogen Oxides
— 3. Remaining Oxygen   NITEP QUEBEC   July 29, 1987

that were used in the dioxin control model. These variables were primary/secondary ratio and total air flow. The third variable was the same for CP (steam rate) but the secondary front/rear air ratio was chosen to 'fine tune' the model for CB.

As with dioxins and furans, the upper right of the three CP and CB graphs contain the four points representing poor operating conditions. This again, confirms the original expectations.

A closer examination of Tables 11.12 and 11.13 reveals similar characteristics to those observed for the dioxin and furan models. For example, using combinations of the two variables carbon monoxide and NO_x alone, or with the addition of moisture in the flue gas or lower radiation chamber temperature, a good prediction of dioxins, furans, CP and CB can be made.

Similarly, combinations of adjustments to the three variables (total air flow, primary/secondary air ratio and steam rate) can provide a means to control dioxins, furans and CP emissions. Adjustments of the total air flow and primary/secondary air ratio can be used to control CB emissions, as for control of dioxins, furans and CP. However, the secondary front/rear air ratio would be used as the third variable to fine tune the control of CB rather than steam rate.

11.4.5 Polycyclic Aromatic Hydrocarbons (PAH) and Polychlorinated Biphenyls (PCB)

PAH and PCB showed a number of similarities in their regression models. Both of these organics have distinctly different models from those of dioxin, furan, CP and CB. The only characteristic that these two organics have in common with the others is that the best prediction models were those involving NO_x. This can be seen by the narrower residual bands, as shown in Figure 11.14A and B, and the higher r^2 values (0.73 and 0.62, respectively). Unlike the other organics models, these models did not use carbon monoxide as a variable. Both prediction models used NO_x, oxygen and lower radiation chamber temperature as shown in Figure 11.14. Figures 11.14A and C show that the four test points representing the poor operating conditions (3, 4, 14 and 15), are scattered randomly over the range of the graph. In addition, most of the other points are clustered near the origin in a random pattern. This means that, despite the quite respectable r^2 values, there is insufficient predictive power in these models.

The prediction models not involving NO_x both have relatively low r^2 values (0.41 and 0.28, respectively) and both used lower radiation chamber temperature, oxygen and carbon monoxide. These values were considered too low for use in these models and thus were rejected. Accordingly, no suitable surrogates were found for PAH or PCB.

The control model for PAH has a reasonable r^2 value (0.63) while the control model for PCB has a very low r^2 value (0.27). Figures 11.14B and D show that the four points that represent the poor operating conditions (3, 4, 14, and 15), are scattered randomly over the range of the graph and most of the other points are clustered near the origin. Accordingly, these control models demonstrated that these variables are inadequate to control emissions of PAH or PCB.

Table 11.12
Total CP Correlations

A. TOTAL CP (ng/Sm3 @ 12% CO2) vs MONITORING VARIABLES
NITROGEN OXIDES as a variable

VARIABLE	UNITS	1	2	3	4
r2		0.56	0.85	0.86	0.87
CARBON MONOXIDE	ppm	125	123	123	129
NITROGEN OXIDES	ppm		197	162	156
LOWER RADIATION CHAMBER TEMP.	deg C			-14.8	-24.8
MOISTURE IN FLUE GAS	%				818
OXYGEN IN FLUE GAS (DRY)	%				
INTERCEPT		4800	-34300	-13400	-14500
C(p)		13.9	1.13	2.56	4.02

Best Fit Prediction Equation
Total CP = Carbon Monoxide x 1.23 + Nitrogen Oxides x 162 - Radiation Chamber Temp. x 14.8 - 13400

B. TOTAL CP (ng/Sm3 @ 12% CO2) vs. OPERATING PARAMETERS
STEAM RATE INCLUDED

VARIABLE	UNITS	1	2	3	4
r2			0.50	0.77	0.89
PRIMARY AIR FLOW	m3/min	57.6			-37.6
SECONDARY AIR FLOW	m3/min		77.3		
PRIMARY/SECONDARY AIR DIST. RATIO			4600	2980	3960
STEAM RATE	Tonnes/hr.			-749	-7.67
TOTAL AIR FLOWS	m3/min			41.8	65.0
SECONDARY F/R COMB. AIR DIST. RATIO					
INTERCEPT		-10800	-16600	-1120	-360
C(p)			5.40	1.53	3.27

Best Fit Control Equation
Total CP = Total Air Flows x 41.8 + Primary/Secondary Air Ratio x 2980 - Steam Rate x 749 - 1120

Table 11.13
Total CB Correlations

A. TOTAL CB (ng/Sm3 @ 12% CO2) vs MONITORING VARIABLES
NITROGEN OXIDES as a variable

VARIABLE	UNITS	1	**	2	**	3	4
r2		0.62	**	0.87	**	0.87	0.90
CARBON MONOXIDE	ppm	48.7	**	48.3	**	49.3	53.0
NITROGEN OXIDES	ppm		**	68.1	**	75.6	65.7
OXYGEN IN FLUE GAS (DRY)	%		**		**	-206	-995
LOWER RADIATION CHAMBER TEMP.	deg C		**		**		-16.5
MOISTURE IN FLUE GAS	%		**		**		
INTERCEPT		2550	**	-11000	**	-10300	15800
C(p)		25.8	**	5.24	**	6.79	6.40

Best Fit Prediction Equation
Total CB = Carbon Monoxide x 48.3 + Nitrogen Oxides x 68.1 - 11000

B. TOTAL CB (ng/Sm3 @ 12% CO2) vs OPERATING PARAMETERS
STEAM RATE INCLUDED

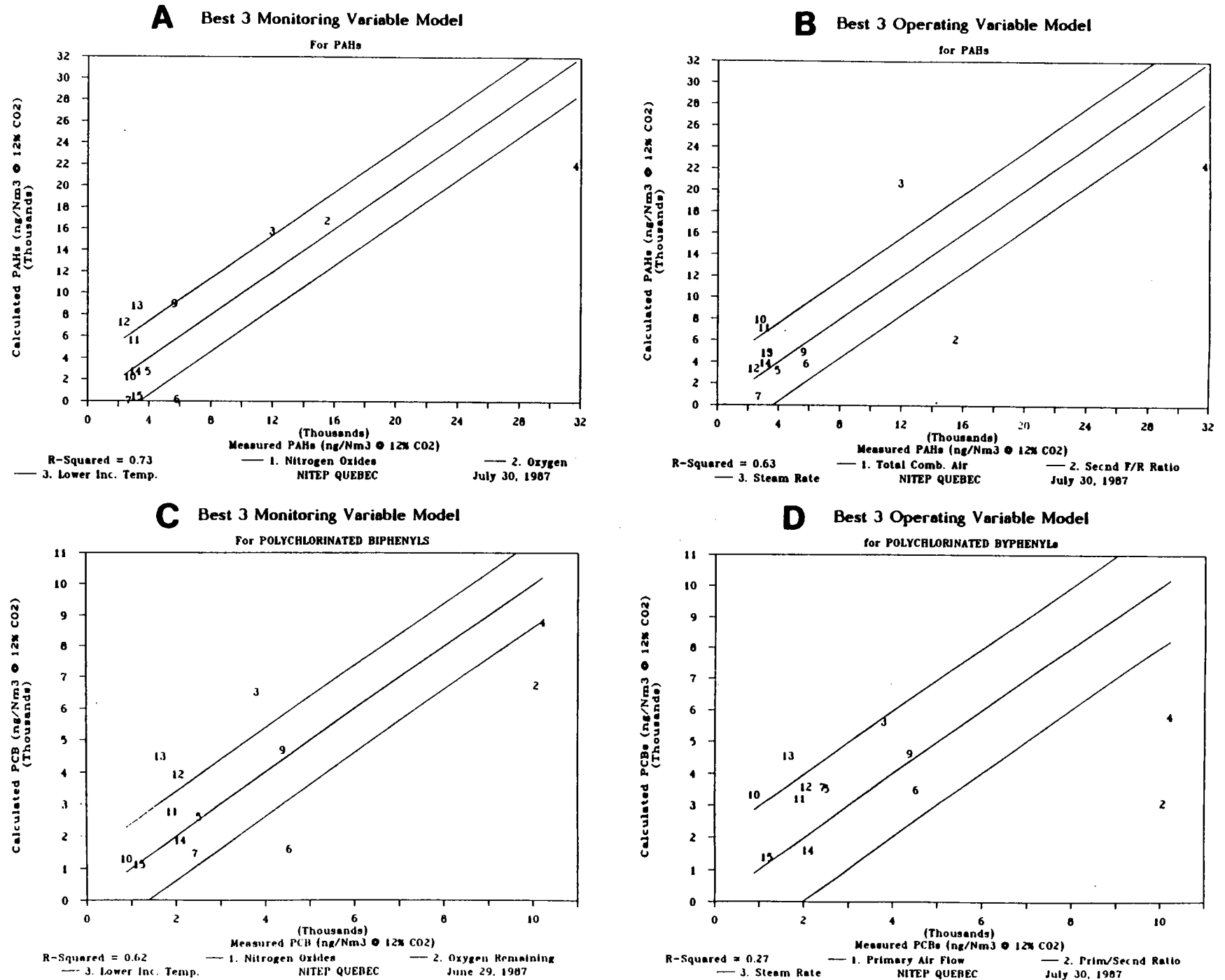| VARIABLE	UNITS	1	2	**	3	**	4
r2		0.67	0.77	**	0.82	**	0.84
PRIMARY AIR FLOW	m3/min	24.9		**		**	-19100
TOTAL AIR FLOWS	m3/min		14.0	**	15.6	**	19100
PRIMARY/SECONDARY AIR DIST. RATIO			970	**	772	**	1350
SECONDARY F/R COMB. AIR DIST. RATIO				**	-1770	**	
SECONDARY AIR FLOW	m3/min			**		**	-19100
STEAM RATE	Tonnes/hr.			**		**	
INTERCEPT		-4520	-5720	**	-4550	**	-7350
C(p)		7.97	4.96	**	4.22	**	5.36

Best Fit Control Equation
Total CB = Total Air Flows x 15.6 + Primary/Secondary Air Ratio x 772 - Secondary F/R Ratio x 1770 - 4550

Figure 11.14 : PAH & PCB Correlations

A Best 3 Monitoring Variable Model

For PAHs

R-Squared = 0.73 — 1. Nitrogen Oxides — 2. Oxygen
— 3. Lower Inc. Temp. NITEP QUEBEC July 30, 1987

B Best 3 Operating Variable Model

for PAHs

R-Squared = 0.63 — 1. Total Comb. Air — 2. Secnd F/R Ratio
— 3. Steam Rate NITEP QUEBEC July 30, 1987

C Best 3 Monitoring Variable Model

For POLYCHLORINATED BIPHENYLS

R-Squared = 0.62 — 1. Nitrogen Oxides — 2. Oxygen Remaining
— 3. Lower Inc. Temp. NITEP QUEBEC June 29, 1987

D Best 3 Operating Variable Model

for POLYCHLORINATED BYPHENYLs

R-Squared = 0.27 — 1. Primary Air Flow — 2. Prim/Secnd Ratio
— 3. Steam Rate NITEP QUEBEC July 30, 1987

11.5 SUMMARY

The regression modelling presented in this chapter clearly demonstrated that it can be an effective method for describing, estimating, and predicting emissions of concern. In addition, it was demonstrated that modelling could be an important tool for controlling emissions through proper incinerator operation. The following is a brief summary of the most important findings.

11.5.1 Simple Linear Regression

The best prediction model to determine the concentrations of dioxins, furans, CP, CB, and particulates employing only one monitoring variable was carbon monoxide concentration in the exhaust gas. However, for PAH and PCB concentrations, the best prediction model used NOx concentration in the exhaust gas. A summary of the best simple linear regression determination coefficients (r2) for the Prediction Models, are provided in Table 11.14. The r^2 values for the organic and particulate prediction models range from 0.51 to 0.67, indicating a strong relationship but not sufficiently strong for the purposes of this study. Therefore, a significantly better prediction model was required. For this reason, multiple regression analysis was eventually employed.

TABLE 11.14
SUMMARY OF BEST SIMPLE REGRESSION
COEFFICIENTS OF DETERMINATION
FOR ORGANICS

	Independent Variable		Simple Regression (r^2)	
Type of Emission	Monitoring Variable	Operating Variable	Prediction Models	Control Models
Dioxin	CO	primary air	0.51	0.77
Furan	CO	primary air	0.61	0.55
CP	CO	primary air	0.56	0.50
CB	CO	primary air	0.62	0.67
PAH	NOx	total air flow	0.67	0.40
PCB	NOx	secondary air flow	0.54	0.16
Particulate	CO	primary air	0.64	0.53

Simple regression coefficients for the **Control Models**, showed that the best-fit, one-variable model **for controlling concentrations of the key trace organics in the flue gas such as dioxins, furans, CP, CB, and particulates, employed primary air flow**. As shown in Table 11.14, the **control model** r^2 values for the trace organics and particulates versus primary air, ranged from fair to good (0.50 to 0.77).

The best one-variable **control models** for PAH and PCB used total air flow and secondary air flow, respectively, as independent variables. However, as shown in Table 11.14, these correlations were insignificant, having r^2 values of only 0.40 and 0.16, respectively.

11.5.2 Multiple Linear Regression

A summary of the multiple linear regression models for both predicting and controlling trace organics emissions is presented in Table 11.15.

The best prediction models for dioxins, furans, CP and CB, employed CO and NO_x. The third key variable for both the dioxin and furan **prediction models** was moisture in the exhaust gas. This suggests that CO, NO_x and moisture in the exhaust gas could be effective in predicting dioxins and furans emissions.

Similarly, by monitoring CO, NO_x and the lower radiation chamber temperature, CP and CB predictions can be made. However, for CB, the third variable did not provide any significant improvement.

Table 11.15 also shows the **control models** with the highest r^2 values for dioxins, furans, CP and CB, ranging from 0.77 to 0.89. In all of the above cases, total combustion air and the primary/secondary air ratio were important elements in the models. In three (dioxins, furans, CP) out of the four models, steam rate was utilized as the third variable. This model data suggests that dioxin and furan emissions (also CP) can be controlled by ensuring that appropriate adjustments are made to the total combustion air, primary/secondary air ratio, and the steam rate. Similarly, the three air distribution variables can be used to control CB emissions.

Upon review of the multiple linear regression models for PAH and PCB, distinctly different results were obtained. Adequate prediction and **control models** for these two organics could not be obtained with the data available. Nevertheless their best **prediction models** employed NO_x, oxygen and lower radiation chamber temperature. Although somewhat respectable r^2 values were obtained (such as 0.73 and 0.62, respectively) it was concluded that there was insufficient predictive power associated with these models. All other **prediction models** and **control models** were rejected for similar reasons.

TABLE 11.15
Multiple Linear Regression Organic Models
r^2 Values and Variables

Prediction Models Emission	With NO_x	Control Model
Dioxins	CO O_x H_2O $r^2 = 0.89$	Total Air P/S Ratio Rate $r^2 = 0.89$
Furans	CO NO_x H_2O $r^2 = 0.90$	Total Air P/S Ratio Rate $r^2 = 0.84$
CP	CO NO_x LRC Temp $r^2 = 0.86$	Total Air P/S Ratio Rate $r^2 = 0.77$
CB	CO NO_x -- $r^2 = 0.87$	Total Air P/S Ratio F/R Ratio $r^2 = 0.82$

Notes:

H_2O	=	Moisture in Exhaust Gas
LRC Temp	=	Lower Radiation Chamber Temperature
P/S Ratio	=	Ratio of Primary Air to Secondary Air
Rate	=	Steam Rate
F/R Rate	=	Front/Rear Secondary Air Ratio
--		Identifies model where third variable provided no significant improvement to the model.

12.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the assessment of the findings throughout this report, the following chapter presents a summary of:

- Key conclusions,
- Performance recommendations,
- Recommendations for future test programs, and
- Recommended further work.

12.1 PERFORMANCE CONCLUSIONS

12.1.1 Test Program Conclusions

1. CO concentration in the flue gas provided a good indication of system operation. Operating conditions that generated low CO emissions and maintained steady steam production resulted in low concentrations of trace organic emissions.

2. Exhaust gas emissions of dioxins and furans measured during this program (ie. 19 ng/Sm^3 PCDD and 44 ng/Sm^3 PCDF during good operation at the design burning rate) were within the lower range of values reported in published literature on mass burning incinerators equipped with electrostatic precipitators.

3. Hydrogen chloride (HCI) emissions were between 366 and 565 ppm which are typical for similar North American facilities.

4. Simultaneous sampling of Unit #4 for particulates using the EPA Method 5 and the Hi-Vol sampling method, resulted in good correlations. In addition, Hi-Vol sampling of Unit #1 (1978 unmodified design) and Unit #4 (1986 modified NITEP unit) showed an almost 20 fold lower level of particulate emissions for the modified unit. The emission concentration of unburnt material from Unit #4 was 50% higher than Unit #1.

5. Multiple sampling of refuse collected during PT-14 indicated that there was considerable variation in refuse composition. Multiple analyses of each collected sample indicated that for most compounds, the analytical repeatability was acceptable.

6. Upon close examination of the particle size distributions, no relationship between distribution and the operating mode was apparent.

7. Significantly lower dioxin and furan levels resulted during these tests (ie. on average, 19 ng/Sm³ PCDD, 44 ng/Sm³ PCDF) In comparison to the earlier results from a stack sampling program carried out by the provincial government in December 1985 (ie. on average, 1985 ng/Sm³ PCDD, 476 ng/Sm³ PCDF). The latter program was carried out prior to the modifications discussed in this report.

12.1.2   Simple Regression

1. Dioxin and furan exhaust emissions both showed strong correlations with the following parameters:

    a) CO and particulate emissions;

    b) exhaust gas flow and primary air flow;

    c) chlorobenzene (CB) and chlorophenol (CP) emissions; and

    d) copper exhaust emissions.

2. No correlation was found between dioxin or furan emissions and:

    a) dioxin and furan concentration in the refuse;

    b) PAH and PCB emissions (dioxin did correlate for the good Performance Test runs only); and

    c) lower, upper and boiler inlet temperatures.

3. Particulate emissions correlated with the following:

    a) CO emissions;

    b) exhaust gas flow and primary air flow;

    c) some of the trace organics emissions, namely dioxin, furan, and CB; and

    d) most of the priority metal emissions, such as cadmium, copper and lead.

4. Emissions of selected metals correlated well with CB, CP, dioxin, and furan emissions. No correlations were found between trace organics and mercury emissions nor lower, upper and boiler inlet temperatures. It is believed that the reason for the correlations between the metals and these organics is that these contaminants are generally associated with the particulate material and will consistently vary up or down depending on particulate loads.

5. Lower radiation chamber temperature correlated well with combustion parameters such as O_2 and CO_2 concentrations, yet very poorly with trace organic emissions. O_2 concentrations correlated inversely with process temperatures while CO_2 correlated directly with process temperatures.

6. Primary air flow correlated with the following:

    a) particulate concentration at the precipitator inlet;

    b) trace organic emissions (dioxins, furans, CP, CB); and

    c) metal emissions at the precipitator inlet (Cd, Cu, Ni, Sb, Cr, Zn).

7. Secondary air flow correlated poorly with all the trace organics, particulate, and metal emissions.

8. Strong correlations occurred between CO emissions and dioxins, furans, CB, and CP emissions yet when CO was compared with primary air and flue gas flow, no correlations were observed.

9. Excess air correlated well with all process parameters but did not correlate with trace organic and metal emissions.

10. Strong correlations were found between precipitator ash metal concentrations of Cr, Cu, and Ni and the emission rates of CB, CP, dioxins and furans. This suggests that by monitoring the rate and concentration of metals in the precipitator ash, predictions of exhaust trace organics may be possible.

11. Poor correlations were found to exist between the following:

    a) combustion chamber temperatures with NO_x emissions;

    b) HCl emissions with chlorine concentrations in the refuse; and

    c) HCl emissions with trace organic emissions.

12.1.3   Multiple Regression

1. In general, simple regression models employing only one variable were considered inadequate for either controlling or predicting emissions of dioxins, furans, CB and CP.

2. Based on extensive analysis of the Quebec test data, significant computer models were identified both to predict and to control incinerator emissions of dioxins, furans, chlorobenzenes (CB) and chlorophenols (CP). Coefficients of determination (r^2), which are indicators of the model's strength, ranged from 0.74 to 0.90 for the best fit multiple linear regression models.

3. The prediction models which best characterized trace organic emissions of dioxins, furans, CB and CP used two or three of the following monitored parameters:

    a) CO

    b) NO_x

    c) O_2

    d) H_2O in flue gas

e) lower radiation chamber temperature.

4. The best model to control trace organic emissions used three of the following operational settings:

   a) Total air flow
   b) Primary/secondary air ratio
   c) Steam rate or refuse rate
   d) Secondary air front/rear ratio.

5. Carbon monoxide was determined to be the best single surrogate in the one variable (simple) prediction model for most of the trace organics, with the exception of PAH and PCB.

6. Although NO_x was the best second variable to improve the prediction capabilities of the models, its significance is not clearly understood at this time.

7. If NO_x were excluded from the prediction models, the next important variable would be lower radiation chamber temperature followed by either oxygen or moisture in the flue gas.

8. Primary air flow was the most influential operational setting for the one-variable control models for dioxins, furans, CB and CP.

9. The PCB and PAH models examined contained either a relatively low r^2 value or the data scatter implied a poor predictive model. Thus, no useful models were found for these two groups of trace organics.

10. The models developed for dioxins, furans, CB and CP are consistent with the fact that poor incinerator operating conditions resulted in higher emission concentrations.

12.2 COMBUSTION AND OPERATION CONCLUSIONS AND RECOMMENDATIONS

1. Relatively low concentrations of most emissions resulted under good operating conditions at the three steam rates tested (i.e. 20, 28, and 32 t/hr - 'low', 'design', and 'high', respectively). Good operation was defined as:

   a) relatively low and steady CO concentrations;
   b) a reasonable split of primary to secondary air;
   c) a proper burning bed depth and profile on all three grate zones;
   d) eliminating slugs of refuse by setting up the control system for obtaining the appropriate grate speeds;
   e) avoiding slag build-up on the refractory walls which reduced the effective grate area;

f) minimizing flame impingement on the boiler inlet tubes; and

g) maintaining a good primary air distribution to all the grates.

2. In general, an effort to improve ash quality (ie. no visible burnables) using high primary air flow and low secondary air flow, resulted in significant increases in emissions.

3. Based on visual observations, when the percentage of total primary (underfire) air to the front burning grate (2A/B) was disproportionately high, particle lift-off occurred and the amount of glowing particles in the upper chamber increased. In addition, as the quantity of air to this zone was increased, the tendency for the flame front to impinge on the boiler tubes increased.

4. Low upper chamber temperatures and high excess air levels occurred when the percentage of total underfire air to the finishing grate was increased above normal. This was due to the lack of burnables on these grate areas. In response, combustion air to the front grate zones was diminished, reducing the burning rate in this area. As a result, the grate bed depth deepened, resulting in a decline in ash quality (i.e. an increase in burnables discharged into the quench tank).

5. Slag formation on the lower furnace walls appeared to be caused by excessively high primary air flows. This condition usually occurred when the "top" or upper furnace radiation chamber temperatures were low. The excessively high primary air flows increased particulate lift-off and locally increased the temperature in the lower furnace zones, which in turn promoted slagging on the walls near the burning grate.

6. Refuse bed depth on the grate indirectly establishes the amount of primary air required. For example, for a specific steam requirement, a thick refuse bed requires less primary air to supply the energy necessary to provide the steam demand. With the increased refuse bed depth, the primary air decreases, resulting in incomplete combustion. In turn, the amount of unburned material in the ash increases. Refuse bed depth is therefore a significant parameter to regulate in order to control the efficiency, emissions, and ash quality.

7. Rapid grate speed changes resulted in increased short-term CO excursions. Under automatic control, sudden increases in grate speed occasionally occurred when steam demand fell. Accordingly, excessive swings in steam demand should be avoided.

8. Limits on the primary air supply, rate of increase of grate speeds, combustions temperatures, and O2 levels should be established to override the steam control setting. This would avoid many of the CO spikes that occurred.

9. Based on visual observations of the ash quality, manual control of the finishing grate speed resulted in an improvement of ash quality (fewer burnables in the ash) as compared to automatic speed control.

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12.3 RECOMMENDATIONS

12.3.1 Recommendations for Future Test Programs

1. The overnight turnaround of data is essential in establishing the success of each test and setting new parameters for subsequents tests.

2. Inputs must be obtained from Quality Control personnel to avoid costly errors.

3. Extensive planning and anticipation of problems is important in minimizing difficulties in the field. Extra equipment and additional qualified personnel should be readily available, to avoid costly delays. All computer systems should be installed and software programs tested at least two weeks prior to the start of the field program.

4. Real-time monitoring of both the process and continuous emissions can significantly assist the combustion team, providing useful data for evaluating whether desired process conditions and test parameters are being achieved.

5. Extremely high ash quantities were found in the ultimate and proximate analyses of the refuse. It was suspected that the sampling methodology may have biased the refuse samples with higher ash concentrationa than what existed. Shredding of the refuse (1/4" nominal size) and application of a "splitter" which divides a pile of material into two identical portions is highly recommended. Successive passes through the splitter until the desired sample size is attained would result in a more representative sample.

6. Very high particulate levels were found in the acetone blanks that were used for the probe cleanings of the stack sampling trains, often higher than the collected samples from the probe. The pure acetone used to wash the probes was suspected of deteriorating the plastic sample bottles, after approximately one month's time. Corrective measures were taken to eliminate this problem. Hence, only glass bottles with teflon covers should be used for collection of the sampling train washings.

7. Grab samples of quench tank ash were collected one litre bottles to determine the moisture content. (No attempts were made to obtain a representative sample for composition analysis). A larger sample volume, such as the 5-gallon pails filled during PT-14 and PT-15, is recommended to obtain a more representative sample.

8. Drying, grinding, and shipping the samples each day to their respective laboratories would eliminate much of the lost time spent in handling the samples at the end of the program. Chances of losing a sample or mixing up samples are also greatly minimized.

9. Further developments to the hardware for continuous monitoring of HCl and hydrocarbons are necessary for improved reliability.

10. Displays of all relevant real-time data should also be provided in the control room to assist the combustion expert in assessing incinerator performance.

11. Further study is required to improve the incinerator grate ash sampling procedures.

12.3.2 Recommended Further Work

1. Additional statistical analysis of non-linear relationships for the NITEP Quebec data is suggested to possibly develop additional models and obtain a better understanding of interrelationships between emissions and process parameters. Specifically, further study of the organic data may provide insight into the mechanisms of organic formation and destruction, facilitating the development of standard operating practices to greatly reduce emissions.

2. Further studies should be carried out to attain a better understanding of the interrelationship between CO, combustion temperatures, primary air flows, and air distributions, to facilitate the development of guidelines for municipal waste mass-burning incinerators.